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KEY PRINCIPLES OF A CIRCULAR AND SUSTAINABLE ECONOMY: EMPHASISING RESPONSIBLE RESOURCE MANAGEMENT AND ENVIRONMENTAL CONSERVATION

DAYCHO KHAENAMKHAEW*

Faculty of Humanities and Social Sciences, Nakhon Si Thammarat Rajabhat University, 80280 Nakhon Si Thammarat, Thailand.

**Corresponding author: Daycho_kha@nstru.ac.th*
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Abstract: This study explores the concepts of circular economy, resource management, environmental conservation, and sustainable development goals. A qualitative research approach was employed, with secondary data analysed using documentary research based on Scott's (1990; 2006) guidelines. The study addresses the question: "What are the key principles of a circular and sustainable economy that emphasise responsible resource management and environmental conservation?" Various research tools and data collection methods were utilised, including analysis and review of academic articles, research reports, agency documents, personal accounts, and local news sources. The study focuses on efficient resource allocation and the prevention of resource depletion. Mimicking natural cycles ensures resource regeneration, promotes responsible management and innovation, and recognising the finite nature of resources. Reusing products extends their lifespans, minimises waste, and conserves resources, facilitating a transition away from a disposable culture. Repair plays a crucial role in sustainability by conserving resources and reducing waste. A circular economy promotes the development eco-friendly, long-lasting products while reducing waste and encouraging responsible consumption. Technological and design advancements improve product performance and lifespan, thereby mitigating the environmental impact. Renovating products or assets to near-original condition conserves resources while using fewer materials for the same functionality. Key principles include "7R-U-D": Durability, renewability, reuse, repair, replacement, upgrade, refurbishment, and reduced material use, all of which contribute to a more environmentally friendly and sustainable world.

Keywords: Circular economy, sustainable, resource management, environmental conservation, environmental impact, responsibility to the community and society.

Introduction

The term "Circular Economy" (CE) refers to the development of a sustainable and environmentally friendly economic system. It is based on the principle of utilising natural resources and energy in a sustainable manner without harming the environment while supporting the emergence of social and economic equality globally. Various countries and organisations have introduced policies and measures to foster a CE. These include promoting renewable energy, reducing greenhouse gas emissions, supporting social equity, fostering technological innovation to enhance resource efficiency, and creating business opportunities that encourage environmental conservation. Sustainable development is a two-way process that involves benefiting from the environment and natural resources while taking responsibility for environmental and social well-being. A CE aims to balance economic growth and environmental preservation to ensure a high quality of life for both current and future generations (Elkington, 1997; Sachs, 2015; United Nations, 2015; Raworth, 2017; Nobre & Tavares, 2021).

Although extensive research has examined the barriers and enablers of CE, limited awareness and understanding among individuals, businesses, and policymakers can hinder its adoption and implementation (Cantú *et al*., 2021). The transition to CE practices faces multiple challenges, including substantial initial investments in technology, infrastructure, and training, which can be particularly daunting for smaller organisations. Regulatory barriers such as outdated policies that fail to encourage circularity, further impede progress. Cnsumer preference for disposable products also complicates efforts to promote sustainable consumption patterns.

Additionally, the complexity of supply chain coordination poses a significant challenge to implementing circular practices. The increasing global demand for resources further strains the availability of sustainable materials, with certain critical materials increasingly becoming scarce. Although it is essential to develop efficient recycling, remanufacturing, and waste management infrastructure, this process is resource intensive. Resistance from commercial entities and individuals accustomed to linear economic models, as well as the need to generate demand for circular products and educate consumers, presents further obstacles. Moreover, achieving circularity requires international cooperation and a shift in cultural norms and social attitudes towards consumption and waste (Ghisellini *et al*., 2016; Geissdoerfer *et al*., 2017; Kirchherr *et al*., 2017; Ellen MacArthur Foundation, 2019). Despite these, both barriers and opportunities associated with CE provide a foundation for understanding how stakeholders can address these issues to promote more sustainable economic practices.

Kirchherr *et al*. (2017) provided an overview of the origins and historical development of the CE concept, highlighting key milestones, and discussing future directions. Geissdoerfer *et al.* (2017) explored the relationship between economic growth and resource efficiency within the CE framework, examining how circular practices contribute to both economic development and reduced resource consumption. Ghisellini *et al.* (2016) critically evaluated the CE concept from a theoretical perspective, examining the feasibility of achieving circularity and its sustainability as a paradigm. The Ellen MacArthur Foundation (2019) investigated CE's potential in addressing climate change by reducing greenhouse gas emissions and pollution, contributing to a more sustainable future. Similarly, Bocken *et al.* (2016) studied real-world business models that successfully implemented CE principles, offering practical insights into how organisations can transition to circular practices and achieve economic and environmental benefits. While CE offers a viable path for economic growth and sustainability, addressing theoretical and practical challenges is essential to fully realise its potential in mitigating climate change and fostering a more complete circular economic model.

CE significantly influences policy development due to its potential to generate a wide range of benefits for the economy, society, and environment. Policymakers worldwide are increasingly recognising the advantages of adopting circular principles. Policies based on CE stimulate economic growth by creating new industries and job opportunities in sectors such as recycling, remanufacturing, repair, and sustainable product design (Pascale *et al.*, 2021). Circular practices optimise resource use, driving innovation in sustainable technologies and practices, as well as minimising waste generation, reducing environmental impacts, and mitigating resource scarcity risks. CE policies also enhance product durability, promote social inclusion, and significantly reduce waste generation, resulting in cost-effective waste management. Countries embracing CE principles position themselves as global sustainability leaders, attracting investments and enhancing their reputation while also achieving cost savings in waste management and environmental remediation. CE-based initiatives foster eco-design, waste reduction, and sustainable materials use, contributing to lower greenhouse gas emissions and supporting small-scale entrepreneurship, as well as reducing environmental disparities, particularly benefiting vulnerable communities (Ghisellini *et al*., 2016; Kirchherr *et al*., 2017; Geissdoerfer *et al*., 2017; Ellen MacArthur Foundation, 2019; Rejeb *et al*., 2023). CE policies provide extensive benefits for both the economy and society, along with valuable insights into the potential advantages and strategies for policy development in this field. These include sustainable policy mechanisms for mitigating environmental externalities by developing green projects, making it beneficial to invest in cleaner technology to advance environmental sustainability goals (Khan *et al*., 2022). The relationship between CE, value creation, strategic management, and evolving business models underscores the need for sustainable development (Awan *et al*., 2022). Integrating this section more cohesively is necessary to strengthen the argument for the study's relevance and contribution to existing knowledge. Understanding CE can serve as a valuable alternative for achieving sustainability in local and global business operations (Ul-Durar *et al*., 2023).

The literature review serves as a methodology for this research, providing an overview of various types of reviews, justifying the need for a qualitative study. This study employs various data collection methods, including document analysis of academic articles, research reports, agency documents, personal accounts, and local news sources (Suknarusaithagul *et al*., 2020; Lertgrai *et al*., 2021). This study follows established guidelines for conducting and evaluating literature review (Snyder, 2019) while contributing theoretically to the role of CE in policy development to bridge the gap between the conceptual understanding of circular principles and their practical applications in shaping policies that promote economic, social, and environmental sustainability. By identifying mechanisms for integrating CE principles into policy frameworks, this study provides a comprehensive perspective on operationalising circularity at the policy level.

Existing literature highlights the benefits of CE, including enhanced resource efficiency, reduced environmental impact, economic growth through job creation, and the promotion of sustainable industrial practices. CE plays a pivotal role in addressing resource scarcity, minimising waste, and driving innovation in sustainable technologies. These studies provide a solid foundation for understanding CE as an innovative approach to maximise resource value while reducing waste (Ali *et al*., 2024) and frame CE's contributions in terms of durability, renewability, reuse, repair, replacement, upgrading, refurbishment, and reduced material consumption (Koval *et al*., 2023; Ali *et al*., 2024). However, despite growing research, gaps remain in understanding the specific policy mechanisms and strategies needed to translate CE principles into tangible economic, social, and environmental outcomes. Challenges and opportunities vary across industries, geographical contexts, and socio-economic conditions, requiring further exploration. Policy development dynamics, including stakeholder engagement, policy coherence, and the role of innovation ecosystems in facilitating circular transitions, also require further investigation.

This study addresses a key research question: "What are the core principles of a circular and sustainable economy that emphasise responsible resource management and environmental conservation?" There is still room to refine these principles and enhance their effectiveness in meeting demand. To fill this gap, this study examines policy instruments, frameworks, and governance structures that support the adoption and implementation of CE principles. It also explores how policies can be designed to maximise the benefits of CE while overcoming barriers to circularity and leveraging opportunities for sustainable development.

Literature Review

Circular and Sustainable Economy

The world is currently grappling with climate change, environmental pollution, natural resource depletion, and energy shortages while economic systems are at risk due to potential supply disruptions caused by raw material scarcity. In response, many countries, particularly in the European Union—including Finland, France, and the Netherlands—have emphasised the CE concept. This approach prioritises waste management in both production and consumption by reintroducing used materials into the production process (re-material) or reusing them (reuse). CE offers multiple benefits, including lower product costs, reduced pollution, decreased carbon dioxide emissions, alleviation of raw material shortages, and increased job creation. Consequently, the European Union has adopted the Circular Economy Development Plan as a guideline for member countries to enhance competitiveness and promote sustainable economic growth.

A circular economy is built on three core principles: Preserving and enhancing natural resource capital; maximising resource utility by circulating materials and products; and maintaining system efficiency by identifying and minimising negative impacts. These three principles support the development of a zero-waste economic system, facilitate the transition to renewable energy, and improve production process efficiency. In Thailand, efforts have been made to align national strategies with sustainable development goals by integrating integrate CE principles (Mahasinpaisarn, 2019). The ongoing crises and challenges affecting people, society, the economy, and environment highlight the consequences of an economic model that prioritises profit maximisation through the excessive resource consumption. CE thus emerges as a solution to restore sustainability by managing and optimising resource use, minimising negative environmental impacts, and reintegrating waste materials into production processes.

Organisations can implement a range of circular strategies. However, successfully establishing a CE requires addressing both internal and external barriers. Internal barriers include a lack of awareness of the importance of a CE, inadequate organisational structures and management, limited investment perspectives, weak partnerships with stakeholders, and a lack of readiness for CE initiatives. External barriers include government regulations, market potential, and the level of social participation. To effectively implement a CE, organisations can follow several steps: Clearly define the organisation's CE objectives and goals; develop a comprehensive CE strategy; raise awareness and build internal knowledge; establish a network of partnerships with stakeholders; communicate CE initiatives to customers and the broader society and seek government support for further development. These steps provide a structured pathway for organisations to adopt and promote CE practices, paving the way for sustainable development in the long term (Khan *et al*., 2022; Valeepitakdej *et al*., 2023).

Resource Management

Building collaboration for community resource management involves several key elements: Establishing a shared ideology for stakeholder involvement; designing a collaborative workspace; setting common goals; recognising mutual value; fostering interaction through joint activities; encouraging participation across all sectors under collective leadership; developing agreements for joint community resource management; and continuously reviewing collaborative efforts (Thummakun *et al*., 2023). Strengthening collaboration among both direct and indirect stakeholders requires creating shared workspaces and platforms for knowledge exchange. This approach systematically addresses community resource management challenges and reduce inequalities through fair management practices, ensuring equal access and opportunities for all community members. It also allows for diverse management models tailored to the specific needs and challenges of each community, ultimately establishing a self-sustaining community resource management system (Thummakun *et al*., 2024). Community resource management through design-based learning for sustainable local self-reliance serves as a driving force for community development in various dimensions, including economic self-sufficiency, social and cultural self-reliance, and sustainable natural resource and environmental management. This approach integrates local knowledge and wisdom into daily practices based on the community's context. It demonstrates that learning does not occur independently of social and cultural contexts, but must take place in real-life situations within the community's environment. Design-based learning is not merely about adapting existing knowledge to align with socially accepted norms; it also involves equipping individuals with the knowledge and ability to participate in social activities. Communities must learn to assess and navigate increasingly complex situations, making design-based learning a process that empowers them to achieve self-reliance through continuous learning (Phuwanatwichit & Piriyatachagul, 2020).

Environmental Conservation

Environmental conservation refers to the practice of protecting, managing, and restoring natural ecosystems and resources to ensure sustainability for present and future generations. It encompasses various strategies, from biodiversity preservation and land management to pollution control and sustainable resource use. The core goal is to maintain the health of ecosystems, which include forests, oceans, wetlands, and other natural habitats, by addressing issues such as deforestation, habitat loss, climate change, and overexploitation of resources. Conservation efforts can be categorised into in-situ and ex-situ strategies. In-situ conservation involves protecting species within their natural habitats through measures such as establishing protected areas like national parks and wildlife reserves. Ex-situ conservation, on the other hand, involves the preservation of species outside their natural habitats through facilities such as zoos, botanical gardens, and seed banks (Primack, 2014). One of the key concepts in environmental conservation is the principle of sustainable development, which seeks to meet present needs without compromising the ability of future generations to meet theirs. This principle emphasises balancing economic growth, social equity, and environmental protection. Climate change is a major driver of environmental degradation, making conservation strategies essential to mitigate its impact. Ecosystem restoration, carbon sequestration, and the promotion of renewable energy are all part of the broader conservation strategy to combat climate change (IPCC, 2021). Effective conservation requires collaboration among communities, governments, and international organisations. Initiatives such as the United Nations' Sustainable Development Goals (SDGs) provide a global framework for coordinated action (United Nations, 2015).

Sustainable Development Goals

The SDGs and CE concept are closely interconnected, offering complementary approaches to sustainability. A CE seeks to decouple economic growth from resource use by promoting sustainable consumption and eliminating waste through strategies such as reuse, recycling, and remanufacturing (Ellen MacArthur Foundation, 2014). Adopting a circular approach is fundamental to achieving many of the SDGs, particularly those focused on environmental sustainability and resource efficiency. Goal 12 (Responsible Consumption and Production) is central to the CE framework, as it advocates for sustainable resource management throughout product lifecycles. By extending product life, optimising resource use, and minimising waste, a CE contributes significantly to this goal. Goal 9 (Industry, Innovation, and Infrastructure) also aligns closely with CE principles by encouraging innovation in sustainable production and supporting the development of resilient infrastructures. Similarly, Goal 11 (Sustainable

Cities and Communities) emphasises sustainable urban planning, where circular solutions can reduce material and energy consumption and lower carbon emissions (United Nations, 2015). The transition to a CE also advances Goal 1 (Climate Action) by cutting greenhouse gas emissions through reduced resource extraction and waste generation. Additionally, it supports Goal 14 (Life Below Water) and Goal 15 (Life on Land) by mitigating marine pollution, habitat destruction, and land degradation. Thus, integrating CE strategies into global and local development plans can significantly accelerate progress towards the SDGs (Geissdoerfer *et al*., 2017). Overall, CE provides a practical pathway for addressing the resource-intensive nature of traditional linear economies, supporting a sustainable future that aligns with the core values of the SDGs, ensuring inclusive growth, environmental protection, and long-term prosperity.

Research Methods

This study employed a qualitative research method using documentary research to answer this question: "What are the key principles of a circular and sustainable economy, with an emphasis on responsible resource management and environmental conservation?". Secondary-level documents were analysed, including academic works aligned with the research objectives such as academic articles, research reports, agency documents, personal accounts, and local news sources. Scott's (1990; 2006) criteria for document selection were applied as follows: (1) Authenticity: Selection of secondary documents that are genuine in origin, academically significant, and credible; (2) Credibility: Consideration of secondary documents containing accurate and reliable information; (3) Representativeness: Inclusion of secondary documents that are representative of the same group of documents and can reflect the data being analysed and synthesised; (4) Meaning: Selection of documents that are comprehensible and provide complete information relevant to the research objectives. These documents were verified to ensure accurate interpretation and appropriate contextual implications for the study.

Relevant document sources were identified through searches in the ThaiJo database, Google Scholar, and Scopus, yielding 431 items. The keywords used included "circular economy", "sustainable economy", "resource management", and "environmental conservation". The documents were then filtered based on Scott's (1990; 2006) criteria, resulting in the selection of 70 items. Each document was reviewed at least twice to ensure its relevance. The selected data were then analysed in detail to extract information aligned with the research objectives and to synthesise the findings (Silalaiy *et al*., 2017; Saenphumi, 2023).

Durability in the Context of Circular Economy

Durability in CE emphasises the necessity for economic systems to sustainably utilise resources, prioritising environmental preservation for future generations. It acknowledges the finite nature of resources, incorporating meticulous resource management to prevent depletion and environmental harm. The transition from linear to circular models is essential, promoting the continual reuse, refurbishment, remanufacturing, and recycling of products and materials. This sustainability-centric approach ensures the availability of resources and minimises environmental degradation, aligning with CE's principles of responsible resource management and reduced environmental impacts for long-term sustainability (Pascale *et al*., 2021). Such an approach minimises waste and maximises the value derived from each resource, reducing the strain on the environment. Furthermore, a durable CE fosters both economic and social growth without compromising ecological integrity. Achieving this requires reevaluating business practices and consumer behaviours to align with environmental goals. It encourages innovation and the adoption of sustainable technologies to drive economic prosperity while significantly reducing carbon footprints and environmental impact. The pursuit of durable CE extends beyond immediate benefits, establishing a harmonious and mutually reinforcing relationship between economic development, environmental stewardship, and societal well-being. This vision promotes a world where prosperity does not come at the expense of the Earth's capacity to regenerate, support biodiversity, and provide a high quality of life for present and future generations (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Ghisellini *et al*., 2016; Geissdoerfer *et al*., 2017).

Extended Product Lifespan

Designing durable products is a fundamental principle of sustainable design and a key component of CE. It involves creating long-lasting products that can withstand wear and tear while maintaining functionality over an extended period. This focus on durability provides both environmental and economic benefits by reducing the need for frequent replacements and conserving valuable resources. It is a proactive approach to developing sustainable products that encompasses several strategies and considerations (Cooper, 2004; Bakker *et al*., 2014; Hernandez, 2019). A crucial aspect of durability is selecting high-quality materials capable of withstanding extended use and environmental exposure. Materials should resist corrosion, wear, and degradation while ensuring mechanical strength to endure stress, shocks, and impacts. Durability is further enhanced by proper assembly and construction techniques, ensuring a long operational life without frequent breakdowns or malfunctions. Reliability is a major aspect of durable design, which can be improved by incorporating modular components that are easy to replace or repair, thus, extending their overall lifespan. Repairability reduces waste by minimising the need to discard and replace entire products. Additionally, providing maintenance guidelines helps consumers prolong product lifespans through proper care and upkeep. Educating users about responsible maintenance and usage further enhances product durability.

However, product durability presents both advantages and challenges. Durable products reduce waste and resource consumption by minimising the need for frequent replacements, thereby resulting in the extraction and processing of fewer resources and supporting the goals of sustainable development. Although high-quality materials and designs may involve higher initial costs, their extended operational life can lead to long-term savings. Products designed for longevity tend to perform reliably over time, leading to greater customer satisfaction and loyalty, which in turn strengthens brand reputation and encourages repeat business (Allwood & Cullen, 2012; Kumar & Reinartz, 2016). Furthermore, durable products require fewer repairs, lowering the overall cost of ownership for consumers. The emphasis on longevity and repairability aligns with the principles of CE, where products, components, and materials remain in use for as long as possible (Guide & Van-Wassenhove, 2009; Geissdoerfer *et al*., 2017).

Despite these benefits, there are also challenges associated with product durability. The use of highquality, durable materials increases initial manufacturing costs, which may be passed on to consumers, potentially making such products less competitive in price-sensitive markets. Additionally, long-lasting products may lack the latest technological advancements, leaving consumers with outdated features as newer innovations emerge (Bocken & Short, 2016). In certain cases, manufacturing durable products requires more resources or energy-intensive materials, which may offset some of their environmental benefits. Companies that produce highly durable goods may also face market saturation, as the reduced need for repeat purchases can impact sales. Consequently, businesses may need to shift towards service- and maintenance-based models rather than relying solely on product sales. Furthermore, designing products for durability assumes long-term usability, but if these products fail to meet evolving consumer preferences or needs, they risk becoming obsolete regardless of their extended physical lifespan (Hertwich & Peters, 2009).

Resource Conservation

Designing and manufacturing durable products offers significant advantages for sustainability, as these products require fewer raw materials and less energy throughout their entire lifecycle. The concept of durability aligns with the principles of CE and enhances resource efficiency while reducing the overall environmental impact (Cooper, 2004; Bakker *et al*., 2014; Ghisellini *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019). Durable products are long lasting and do not need to be replaced as frequently as lesser durable alternatives, which reduces demand for raw materials since fewer new products need to be manufactured. This, in turn, helps conserve valuable natural resources such as minerals, metals, and fossil fuels used in the production of consumer goods. The production of new products highly energy-intensive, involving resource extraction, manufacturing, transportation, and packaging. In contrast, durable products reduce the need continuous manufacturing, leading to lower energy consumption over time. The reduced demand for raw materials and lower energy requirements also contribute to a smaller environmental footprint. Additionally, durable products help lower greenhouse gas emissions, reduce pollution, and lessen stress on ecosystems, thereby aligning with sustainability goals and mitigating environmental challenges. By extending the lifespan of products, durable design actively promotes resource conservation and supports the efficient use of materials already in circulation, rather than relying on the continuous extraction of new resources.

Reduced Waste Generation

A key strategy for waste reduction and sustainability is designing and using longer-lasting products. These products generate less waste over their extended lifespans, alleviating pressure on landfills and incineration facilities. This approach aligns with the principles of CE and promotes more responsible and environmentally friendly consumption patterns (Cooper, 2004; Bakker *et al*., 2014; Ghisellini *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019). Durable products do not need to be replaced as frequently as their less durable counterparts, thus significantly reducing the overall volume of waste generated throughout their lifecycle. In addition, longerlasting products help minimise the burden on landfills, which are already facing capacity challenges in several regions. Reduced waste disposal not only conserves valuable land resources, but also reduces the environmental impact associated with landfilling such as leachate production and greenhouse gas emissions. Incineration, another common waste management method, contributes to air pollution and releases harmful substances. By reducing waste generation, durable products lower the demand for incineration, improving air quality and minimising environmental risks. Furthermore, producing fewer new products conserves natural resources, reinforcing CE's objective of maximising the use of existing materials while reducing the need for continuous resource extraction and production.

Consumer Savings

Durable products provide greater value to consumers by offering extended lifespans and requiring fewer replacements, leading to long-term cost savings for consumers and making them an economically attractive choice (Cooper, 2004; Bakker *et al*., 2014; Bocken *et al*., 2016; Hernandez, 2019). Their ability to withstand wear and tear ensures that they last longer than less durable alternatives. Consequently, consumers do not need to purchase replacements as frequently. These align with the principles of frugality and responsible consumption. Although durable products may have a higher initial cost, their lower total cost of ownership, including purchase price, maintenance and replacement expenses, makes them a cost-effective choice. Additionally, longer-lasting products often lead to higher consumer satisfaction by providing reliable performance and value for money.

Environmental Benefits

Increasing product longevity through durability reduces greenhouse gas emissions associated with the different stages of a product's lifecycle, including manufacturing, transportation, and disposal. This sustainable approach aligns with the principles of CE and contributes to environmental conservation (Cooper, 2004; Ghisellini *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019; Ellen MacArthur Foundation, 2019). Because durable products have longer lifespans, they require less frequent manufacturing, reducing reliance on energy-intensive production processes and leading to lower greenhouse gas emissions.

Frequent replacements of products often involve transportation, further contributing to carbon emissions. Long-lasting products reduce the need to transport new items to consumers, thus lowering emissions associated with logistics and distribution. Additionally, the emissions generated during the use phase of a product are spread over a longer period, reducing its annual carbon footprint. Longer-lasting products also generate less waste, which minimises emissions from waste management processes such as landfilling and incineration. By extending the lifespan of products, durability helps mitigate the environmental impact associated with their disposal.

Circular Business Models

Durability is intricately linked to circular business models such as repair, refurbishment, and remanufacturing, which collectively extend product lifecycles and foster a closed-loop system. These approaches not only minimise waste, but also promote sustainability and resource efficiency (Bakker *et al*., 2014; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019; Colombo *et al*., 2021). Durability supports repairability by ensuring that products are designed to allow for easy maintenance and fixing. Repair services for long-lasting products are both feasible and cost-effective, encouraging consumers to repair rather than discard their possessions. Additionally, durable products are more well-suited for refurbishment, as they can be restored to a like-new condition. The refurbishment process involves repairing, cleaning, and upgrading components, allowing products to regain commercial viability. Remanufacturing involves disassembling and rebuilding a product to its original specifications, often using recycled or reconditioned components. Durability is a key factor in successful remanufacturing because products need to be robust enough to undergo multiple cycles of remanufacturing. It facilitates a closed-loop system, where products and materials remain in circulation within the economy for as long as possible. This minimises the extraction of new resources and reduces waste, making it into an environmentally sustainable approach.

In the context of CE, "durability" not only refers to the resilience of products, but also to the long-term sustainability of economic systems and developments that proritise environmental preservation. It promotes the careful use of natural resources and the efficient allocation of materials to prevent resource depletion or environmental degradation. Furthermore, it involves developing an economy that supports economic and social growth without causing harm to the environment or society. Although durability within CE provides numerous advantages in terms of environmental preservation and long-term sustainability, it also presents challenges related to high initial costs, technological limitations, behavioural shifts, and market competition, which must be addressed to ensure its effective implementation.

Renewability in the Circular Economy

One of the key pillars of renewability in CE is the promotion of renewable resources. Renewable resources such as solar energy, wind energy, and sustainably managed forests, naturally regenerate or replenish within a relatively short timeframe. By prioritising renewable resources as primary inputs, CE reduces reliance on finite resources such as fossil fuels and rare minerals, addressing concerns about environmental impact and resource scarcity. In addition, renewability in CE extends to resource recovery and recycling. It promotes the efficient collection, processing, and reuse of materials and products at the end of their lifecycle. This not only reduces waste, but also minimises the demand for virgin resources, thus preserving natural ecosystems and mitigating the environmental degradation associated with resource extraction. Furthermore, CE underscores the importance of regenerative agriculture and sustainable land management practices. These approaches can restore and enhance soil health, biodiversity, and ecosystem resilience, ensuring the long-term viability of agricultural resources while sequestering carbon and mitigating climate change (Bakker *et al*., 2014; Ellen MacArthur Foundation, 2019; European Commission, 2020). In CE, renewability is central to sustainable resource management. It refers to the sustainable use and regeneration of resources that can be naturally replenished over time, ensuring that they are not depleted faster than they can regenerate. This approach aligns with key principles of sustainability, environmental stewardship, and long-term resource availability, promoting a balance between resource use and natural replenishment (Ellen MacArthur Foundation, 2014; European Commission, 2014; Kirchherr *et al*., 2017; Korhonen *et al*., 2018; Luis & Celma, 2020).

Sustainable Management of Renewable Resources

Renewability underscores the importance of managing renewable resources responsibly. This includes resources like forests, fisheries, and agricultural crops, which require careful planning and management to ensure their continued availability. Sustainable forestry practices involve managing forest resources to maintain their biodiversity, productivity, and ecological processes. This includes setting harvest levels below the forest's regeneration capacity, protecting critical habitats, and promoting reforestation efforts. These efforts help sustain the long-term health and availability of forest resources, contributing to carbon sequestration, biodiversity conservation, and the maintenance of ecosystem services. Sustainable fisheries management aims to prevent overfishing and maintain healthy fish populations. This involves setting catch limits based on scientific assessments of fish stocks, safeguarding spawning grounds, and implementing strategies to minimise bycatch. Such practices help preserve marine ecosystems, ensure the long-term viability of fish populations, and support the livelihoods of communities dependent on fishing. In agriculture, renewability involves practices that enhance soil health and fertility, such as crop rotation, cover cropping, and reduced tillage. These techniques improve soil structure, increase organic matter, and promote biodiversity, leading to more resilient and productive agricultural systems. Sustainable agriculture not only ensures a stable supply of food and raw materials, but also contributes to climate change mitigation by sequestering carbon in soils.

Environmental Stewardship

Renewability also encompasses the principle of environmental stewardship, which involves taking responsibility for the health of the environment. By managing renewable resources sustainably, CE aims to reduce the environmental impact of resource extraction and use. This includes minimising habitat destruction, reducing pollution, and conserving biodiversity. Sustainable resource management practices contribute to the overall health and resilience of ecosystems, which are essential for the well-being of all living organisms. The concept of renewability in CE aligns closely with the broader principles of sustainability, emphasising the need to balance resource use with natural regeneration rates, thereby preventing resource depletion and environmental degradation. This approach emsires the long-term availability of resources, allowing them to meet the needs of both present and future generations.

Biomass and Bioenergy

In CE, renewable resources such as biomass play a crucial role in bioenergy, biofuels, and bio-based materials. Responsible harvesting and replanting practices ensure sustainability, aligning with CE's objective of optimising resource efficiency and minimising waste. These resources are integrated into circular systems, where organic waste us composted or repurposed into recyclable or biodegradable products, reducing pressure on non-renewable resources and ecosystems. This approach supports biodiversity and mitigates environmental degradation associated with resource exploitation. Fazzino *et al.* (2023) highlighted the importance of effective waste management in fostering healthy living conditions and mitigating climate change. Their study examined the ue of landfill leachate as a nutrient solution in tne anaerobic digestion of market waste. By filtering out inhibitory substances, the leachate supplied essential nitrogen, stabilising the digestion process.

Even with increased waste input and leachate volume, the system remained stability, producing methane for renewable energy and digestate for fertiliser, thereby closing the waste management loop. Similarly, Ranjbari *et al.* (2022) identified a growing intersection between the economy, bioeconomy, and CE over the past decade, driving the emergence of the circular bioeconomy (CBE). This framework focuses on biomass and organic waste valorisation to create sustainable product lifecycles. Their research highlighted key themes such as biological conversion technologies, CE implementation, environmental studies, and food waste management. Recent studies have explored innovations like biochar production, insect biorefineries, and lifecycle assessments for bio-waste treatment. These advancements support both academic research and practical applications, aiding the implementation of CE principles in bio-based waste management.

The "renewability" aspect of CE is a fundamental principle that underscores the need to design economic systems and processes that enable resources to regenerate naturally without depleting or permanently damaging the environment. It ensures that resources within the CE model can be renewed over time, securing sustained economic and environmental benefits. This aspect of CE embodies sustainability and resilience by promoting economic systems that mimic natural cycles, where resources are sourced and utilised in ways that facilitate their replenishment. This approach recognises the finite nature of certain resources, while acknowledging the potential for others to be renewed through natural processes, innovation, and responsible management. Although the renewability aspect of CE offers significant advantages in terms of environmental sustainability, resource conservation, and economic resilience, it presents challenges related to technological limitations, transition costs, limited availability of renewable resources, and potential ecosystem impacts that need to be carefully considered and addressed.

Reuse in the Circular Economy

Reuse involves keeping products and materials within the economic system for as long as they remain functional and fit for use. It marks a departure from the traditional linear economy model, where products have short lifespans and are discarded after use. Instead, CE promotes designing and manufacturing products with durability and reusability in mind, allowing them to be easily refurbished, remanufactured, or repurposed. The concept of reuse can take several forms (Tukker & Tischner, 2006; Geng *et al*., 2012; Ellen MacArthur Foundation, 2014; Bakker *et al*., 2014; Sarkis, 2023), which include direct reuse, refurbishment, remanufacturing, repurposing, and sharing models.

Direct Reuse

In the context of CE, direct reuse refers to using a product again without significant modification or refurbishment. This practice extends a product's lifespan and minimises waste by allowing others to continue using it. Reuse applies to a wide range of goods, from clothing to electronics, playing a crucial role in reducing resource consumption and environmental impact (Geng *et al*., 2012; Bakker *et al*., 2014; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019). Direct reuse involves transferring products to others for further use, typically without substantial alterations. This reduces the demand for new manufacturing, thus, conserving resources. Examples of reuse include selling or donating used clothing, electronics, furniture, and appliances to individuals, charities, or organisations. These items can continue serving their intended purpose even after their original owners no longer need them. Reuse is a direct method to reduce waste generation by keeping products in circulation rather than discarding them. It aligns with CE's objective of minimising the environmental impact associated with resource extraction and production. Beyond its environmental benefits, reuse also offers economic advantages by making products more affordable for consumers. Additionally, it fosters community engagement through sharing and donation initiatives.

Refurbishment

Refurbishment involves repairing and restoring products to their original condition, thereby extending their lifespan. This applies to various products, including electronics, furniture, and even vehicles (Cooper, 2004; Geng *et al*., 2012; Bakker *et al*., 2014; Geissdoerfer *et al*., 2017; Hernandez, 2019). A key aspect of refurbishment is repair, which focuses on fixing and restoring products that have experienced wear and tear, or malfunctions, returning them to their original working condition. This process can include replacing damaged components, addressing issues, and ensuring that the products function as intended. Repairing products extends their useful life, reducing the need for frequent replacements, conserving resources and reducing waste, which in turn mitigates thee nvironmental impact associated with disposal. Repair services apply to a wide range of products, including smartphones, laptops, household appliances, furniture, and vehicles. Repairs can be carried out by skilled technicians, individuals, or specialised repair shops. Repair is cost-effective as it helps consumers avoid the expense of purchasing new products while also promoting sustainability by reducing the overall demand for new manufacturing. It aligns with CE's objective of maximising resource efficiency and minimising waste.

Remanufacturing

Remanufacturing is an extensive process in which products are disassembled and refurbished or replaced with new components, and then reassembled to function like new. This practice is commonly employed in the automotive industry for parts such as engines and transmissions (Sundin & Bras, 2005; Bakker *et al*., 2014; Ferguson & Browne, 2019). The process begins with disassembly, where products are carefully taken apart, and individual components are inspected for wear or damage. Worn or faulty components are either refurbished or replaced with equivalent parts; this process could involve cleaning, re-machining, or reconditioning components to meet original specifications. Stringent quality control measures, including evaluation and calibration ensure that the remanufactured components or products meet or exceed the performance and comply with the safety standards of new items. Once all components are refurbished or replaced, the product is reassembled to its original specifications. The remanufactured product should function indistinguishably from a new one. Remanufacturing conserves resources by extending product lifespan and reducing the demand for new manufacturing. It aligns with the principles of CE by maximising the use of existing resources.

Repurposing

Repurposing involves transforming a product into something entirely different from its original use, extending its useful life (Korhonen *et al*., 2018). This process requires finding new and innovative methods to utilise products or materials for purposes other than their original design, often requiring creativity and adaptability to identify alternative uses. Items that may have been discarded or considered obsolete can be used to generate products with new functions and purposes. Repurposing aligns with the principles of CE by conserving resources. Repurposing can be observed in different contexts, such as upcycling old furniture into unique home decor, converting shipping containers into affordable housing units, or using discarded industrial equipment for artistic installations.

Sharing Models

Sharing platforms such as ride-sharing and equipment-sharing services play a vital role in CE as they promote the shared use of a single product or resource among multiple users, reducing the need for individual ownership. This approach aligns with the principles of resource efficiency and sustainable consumption (Mont, 2004; Botsman & Rogers, 2010; Cohen & Kietzmann, 2014; Hamari *et al*., 2016; Sundararajan, 2016). Sharing platforms facilitate shared access to products or resources, allowing multiple users to utilise a single item. For example, ride-sharing services enable users to share trips in the same vehicle while equipment-sharing platforms allow individuals and businesses to share tools and machinery.

Pooling the use of a product optimises resource utilisation, thereby reducing the overall number of items needed to meet the same demand and resulting in lower resource consumption and reduced environmental impact. Sharing platforms promote a shift from individual ownership to shared access, leading to fewer purchases, reduced clutter, and decreased maintenance and storage requirements for individuals and organisations. They are also cost-effective, as users can access resources on a pay-as-you-go basis rather than making large upfront investments. This can be economically advantageous for both providers and users.

The benefits of reuse in the CE are multifaceted: Reducing waste generation, conserving resources, and lowering the overall environmental impact associated with the manufacturing of new products. Additionally, it has economic advantages, including creating jobs in refurbishment and remanufacturing industries, and potentially reducing the cost of goods for consumers. The concept of reuse in CE is a fundamental principle that extends a product's lifespan by enabling its multiple uses, either in its original form or after refurbishment. It promotes a shift away from the disposable culture of "take-make-dispose" towards a more sustainable approach, where products and materials are utilised for as long as possible. Overall, although reuse offers significant advantages, it presents challenges related to limited applicability, quality concerns, infrastructure requirements, and the need to promote consumer behaviour change.

Repair in the Circular Economy

The concept of repair in CE highlights the importance of extending the lifespan of products and components by fixing or refurbishing them instead of discarding them when they break or become obsolete. Repair is a fundamental strategy within CE as it contributes to resource conservation, waste reduction, and sustainable consumption (Bakker *et al*., 2014; Bocken *et al*., 2016; Hernandez, 2019).

Prolonging Product Lifespan

Repair focuses on designing durable and long-lasting products with easily replaceable or repairable components. Repair-focused design prioritises robust materials and construction methods that resist wear and tear over time. Components are designed for easy replacement or repair when damaged or obsolete, promoting maintenance and extending product life. Repair-oriented design reduces resource consumption by minimising the need to manufacture new products. It aligns with the principles of CE of maximising resource efficiency and minimising waste. Repair practices are in direct contrast to planned obsolescence, in which products are intentionally designed with a limited lifespan to encourage frequent replacements (Cooper, 2004; Bakker *et al*., 2014; Geissdoerfer *et* *al*., 2017; Korhonen *et al*., 2018; Hernandez, 2019). Repair promotes a shift away from the unsustainable practice of planned obsolescence.

Local Repair and Service Ecosystems

Local repair and service ecosystems are encouraged to thrive in CE. These ecosystems include repair shops, technicians, and communities equipped to repair various products. They reduce the need for long-distance transportation and contribute to local job creation (Tukker & Tischner, 2006; Botsman & Rogers, 2010; Hawken *et al*., 2013; Cohen & Kietzmann, 2014; Hamari *et al*., 2016). Local repair and service ecosystems consist of networks of repair shops, technicians, and community-based repair initiatives. These entities diagnose, fix, and maintain a wide range of products, from electronics to household appliances. The presence of accessible repair facilities within communities minimises the need to transport products over long distances to centralised repair centres, which not only reduces transportation-related emissions, but also conserves energy and resources. Developing local repair ecosystems also creates job opportunities within communities. Skilled technicians and repair professionals are essential for maintaining and extending the lifespan of products, contributing to local economic sustainability. Repairing and servicing products locally promotes resource efficiency by extending the life of products and reducing the demand for new manufacturing. This aligns with the goals of CE of waste reduction and responsible resource use.

Consumer Engagement

CE encourages consumers to actively engage in repair activities such as do-it-yourself (DIY) repairs or seeking assistance from local repair shops. This empowers consumers to opt for more sustainable choices by extending the lifespan of their possessions (Mont, 2004; Cooper, 2012; Cohen & Kietzmann, 2014; Bocken *et al*., 2016). Consumer participation in maintaining and repairing their belongings fosters a sense of responsibility for the products they own and reduces reliance on disposable or short-lived items. Consumers are encouraged to learn basic repair skills and undertake simple repairs such as sewing, fixing electronics, or patching furniture. The increasing availability of online repair guides and tutorials has further facilitated access to DIY repair knowledge. For more complex repairs requiring specialised skills or tools, consumers are encouraged to seek assistance from local repair shops and professionals. Supporting local repair businesses not only product lifespans, but also contributes to the local economy. By prolonging product use, repair activities help reduce waste, conserve resources, and mitigate the environmental impact associated with manufacturing new items.

Manufacturer Responsibility

Manufacturers are encouraged to take responsibility for the repairability of their products by providing repair manuals, spare parts, and repair services, making it easier for consumers to extend product lifespans (Cooper, 2012; Bakker *et al*., 2014; Geissdoerfer *et al*., 2017; Korhonen*et al*., 2018; Hernandez, 2019).

Within CE, manufacturers are expected to design products with repairability in mind, ensuring products can be disassembled, repaired, and maintained throughout their lifespan. Providing repair manuals, guides, or instructional videos empowers consumers with the knowledge and resources needed to perform basic repairs. Ensuring the availability of spare parts allows consumers to replace worn or damaged components rather than discarding an entire product due to the failure of a single part. Additionally, some manufacturers offer repair services directly or through authorised repair centres, ensuring consumers have access to professional repair expertise. By taking responsibility for repairability, manufacturers reduce the likelihood of products becoming obsolete due to minor issues, aligning with CE's objective of extending the lifespan of products.

Circular Business Models

Companies are exploring circular business models such as "product as a service", where customers lease or subscribe to products rather than purchasing them outright. In such models, manufacturers have a vested interest in ensuring the longevity and repairability of their products (Corvellec *et al*., 2022; Cooper, 2012; Bakker *et al*.„ 2014; Geissdoerfer *et al*., 2017; Korhonen *et al*., 2018; Hernandez, 2019). Manufacturers in CE are encouraged to design products with repairability in mind, considering the ease with which they can be disassembled, repaired, and maintained throughout their lifespan. Providing repair manuals, guides, or instructional videos enables consumers to perform repairs themselves and empowers them with the knowledge and resources required to extend the life of their products. Additionally, ensuring the availability of spare components allows consumers to replace worn or damaged parts rather than discarding entires product due to a single failure. Some manufacturers offer repair services directly or through authorised repair centres, ensuring consumers access to professional repair expertise. These practices reduce the likelihood of premature obsolescence due to minor issues, aligning CE principles of extending the lifespan of products.

Repair plays a crucial role in achieving sustainability, resource conservation, and waste reduction within CE. However, its effective integration into product design, consumption, and business models faces challenges, including feasibility, technological constraints, consumer behaviour, and market dynamics. Addressing these barriers is essential for maximising the benefits of repair within CE frameworks.

Replacement in the Circular Economy

In CE, replacement refers to the responsible and sustainable substitution or exchange of products, components, or materials when they reach the end of their useful life or when more sustainable alternatives become available. This approach prioritises eco-friendly, efficient, and longer-lasting options (Tukker & Tischner, 2006; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019).

Sustainable Product Alternatives

Replacement in CE involves identifying and selecting products or materials with lower environmental impacts or longer lifespans. Replacement strategies focus on minimising environmental impacts and involve assessing the environmental footprints of products or materials and seeking sustainable alternatives. One aspect of replacement is the substitution of materials, for example, replacing plastic packaging with biodegradable or recyclable materials, or using renewable resources instead of finite ones. Replacement also entails selecting products or materials with longer lifespans and involves transitioning from disposable or short-lived items to durable, long-lasting alternatives.

Additionally, it includes substituting single-use items with reusable alternatives, for example, replacing disposable water bottles with refillable containers, or opting for cloth shopping bags instead of single-use plastics. Making informed replacements promotes efficiency, which aligns with the principles of CE of maximising resource use and minimising waste (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Kirchherr *et al*., 2017; Geissdoerfer *et al*., 2017; Korhonen *et al*., 2018).

Upgradability

Products in CE are designed for upgradability, allowing consumers to replace outdated or inefficient components with newer, more efficient ones, extending the overall lifespan of the product and reducing waste (Bakker *et al*., 2014; Geissdoerfer *et al*., 2017; Hernandez, 2019). Modular product design enables easy replacement or enhancement of components such as processors, memory, and batteries, or other parts that could become outdated over time. Upgradability ensures that products remain functional and up-to-date for longer periods, allowing consumers to make incremental improvements to their products rather than discarding them upon the availability of novel features. This approach maximises resource efficiency, reduces the need for frequent replacements, and conserves valuable materials, aligning with the principles of sustainable resource management. Upgradability also empowers consumers to decide when and how to enhance their products, providing a personalised and cost-effective approach to stay current with technological developments. One of the significant benefits is the reduction in electronic waste (e-waste), as upgrading individual components decreases the overall volume of discarded electronics.

Technological Advancements

Replacement can involve leveraging technological advancements such as transitioning from conventional energy sources to renewable energy systems or adopting more energy efficient appliances (Sovacool & Dworkin, 2015; Wiedmann, 2009). Upgrading outdated systems with more sustainable alternatives reduces environmental impact. For example, replacing fossil fuels with renewable energy sources such as solar or wind power, lowers greenhouse gas emissions and promotes cleaner energy production. Similarly, replacing energy-intensive appliances with energy-efficient models reduces energy consumption, lowers utility costs, and minimises the environmental footprint of energy production. Technological replacement strategies contribute to resource conservation by reducing the demand for non-renewable resources and minimising environmental degradation. Embracing these advancements for sustainability supports environmental preservation, climate change mitigation, and the overall well-being of both current and future generations.

Innovation and Research

Ongoing research and innovation drive the development of sustainable replacements for existing materials, processes, and technologies (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Kirchherr *et al*., 2017; Hernandez, 2019; Koval *et al*., 2023). These efforts span multiple disciplines, including materials science, engineering, and environmental science. Researchers focus on creating environmentally friendly alternatives such as biodegradable plastics, sustainable building materials, and eco-friendly textiles. Innovation also enhances manufacturing processes, reducing energy consumption, waste generation, and environmental impact. Advances in technology contribute to sustainability by improving product efficiency, such as the development of energy-efficient appliances and low-emission transportation. By prioritising environmental considerations, research and innovation help mitigate resource depletion, pollution, and greenhouse gas emissions.

Consumer Awareness

Educating consumers on the benefits of responsible replacement is essential to encourage consumers to make informed choices when replacing products or upgrading systems, leading to more sustainable consumption patterns (Hines *et al*., 1986; Steg & Vlek, 2009; Gifford & Nilsson, 2014; Thøgersen, 2019; Mies & Gold, 2021). Raising awareness about the environmental and economic impacts of consumption choices allows consumers to learn and consider factors such as product durability, energy efficiency, and environmental footprint when making replacement decisions. Consumer education can drive lifestyle changes that prioritise responsible replacement, including selecting products with longer lifespans, opting for energy-efficient appliances, or embracing circular business models such as product leasing. By fostering sustainability literacy, consumer education equips individuals with the knowledge and skills needed to make environmentally responsible choices, reducing waste and minimising the environmental impact of product disposal.

Integrating replacement strategies into product design, business models, and consumer behaviour plays a critical role in achieving sustainability goals.

Upgrade in the Circular Economy

In CE, upgrade refers to improving, enhancing, or modernising products, systems, or technologies to increase their efficiency, sustainability, and alignment with circular principles. It involves upgrading existing assets rather than replacing them entirely, contributing to resource conservation, and reducing waste (Bocken *et al*., 2016; Kirchherr *et al*., 2017; Hernandez, 2019).

Product Enhancement

Upgrading products involves incorporating recent technologies, materials, or design features to improve their performance and durability, and reduce their environmental impact. For example, upgrading electronics to enhance energy efficiency or adding features for easier repair (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Kirchherr *et al*., 2017; Geissdoerfer *et al*., 2017; Hernandez, 2019).

Product upgrades leverage technological advancements to enhance functionality and lifespan while ensuring ease of repair and maintenance, aligning with the CE principles of repairability and resource efficiency. By reducing the need for frequent replacements, upgrades minimise waste and promote sustainability. Additionally, enhanced products contribute to lower energy consumption, reduced greenhouse gas emissions, and a decreased environmental footprint, supporting a more sustainable future.

Software and Firmware Updates

In the digital age, upgrading often includes software and firmware updates to optimise the functionality of products such as smartphones or appliances. These updates can add new features, improve security, and extend the life of the device (Mont, 2002; Tukker, 2004; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Antikainen *et al*., 2021). Digital upgrading enhances product functionality through software or firmware updates, which can be applied to different digital devices, including smartphones, computers, and smart appliances. Updates often introduce new features, capabilities, and improvements, enhancing user experience and the product's value, extending the useful life of the device, and making it more versatile and adaptable to changing needs. In addition, regular updates address security vulnerabilities and performance issues ensuring that devices remain safe from cyber threats and continue to perform optimally over time. Digital upgrading is a resource-efficient method to extend product lifespans without the need for physical hardware replacements, aligning with the CE principles of reducing waste and maximising resource use, as well as the associated environmental impact of electronic disposal.

Modular Design

Modular design allows products be easily upgraded by replacing or adding modules, enabling consumers to adapt their products to changing needs or technological advancements without discarding the entire item (Ellen MacArthur Foundation, 2013; Bakker *et al*., 2014; Geissdoerfer *et al*., 2017; Hernandez, 2019). Products designed with modular components such as processors, memory, batteries, sensors, or other functional units, offer flexibility for customisation and upgrades so that the products align with consumers' specific requirements. By replacing or upgrading modules, the overall lifespan of a product can be significantly extended. This reduces the need for frequent replacements and conserves resources. Modularity promotes resource efficiency by maximising the use of existing components while minimising the environmental impact of manufacturing and disposal. The concept aligns with circular business models such as repair, refurbishment, and remanufacturing, facilitating a closed-loop system, where components can be reutilised.

Energy Efficiency

Energy efficiency upgrades reduce energy consumption, minimise environmental impact, and generate financial savings, reinforcing their importance within a circular framework (Keirstead, 2012; Allouhi *et al*., 2015; Ellen MacArthur Foundation, 2019; Madushika *et al*., 2023; Tosida *et al*., 2024). Upgrading within CE often involves adopting energy-efficient technologies and practices, including replacing or retrofitting existing systems and components with more efficient alternatives. In construction, this may include improving insulation, installing energy-efficient windows, or upgrading Heating, Ventilation, and Air Conditioning (HVAC) systems. A common example is replacing traditional lighting with LED technology, which consumes less energy, lasts longer, and reduces greenhouse gas emissions. Energy efficiency upgrades support resource conservation by reducing energy consumption, consequently lowering the demand for fossil fuels and minimising environmental pollution. Additionally, these upgrades often reduce utility bills and a favourable return on investment over time.

Consumer Engagement

Encouraging consumers to actively engage in upgrading their possessions is a key aspect of CE. This includes providing information on available upgrades or incentivising responsible upgrading practices (Tukker & Jansen, 2006; Steg & Vlek, 2009; Gifford & Nilsson, 2014; Thøgersen, 2019; Khan *et al*., 2022). In a CE, consumers are empowered to make informed decisions about upgrading their possessions by receiving information about the available upgrades and environmental benefits of responsible upgrading. Multiple incentives such as trade-in discounts or tax incentives for energy-efficient upgrades, can encourage sustainable upgrading choices. A culture of sustainable consumption fosters awareness of the environmental impact of possessions and promotes decisions aligned with circular principles. Providing clear product information on upgrade options and their benefits helps consumers make informed choices. Education and awareness campaigns further reinforces the environmental advantages of upgrading such as reduced resource consumption and waste generation.

While upgrading plays a significant role in sustainability, resource conservation, and waste reduction, challenges such as technological limitations, consumer behaviour, market dynamics, and cost considerations must be addressed to maximise its effectiveness in advancing a circular and sustainable economy.

Refurbishment in the Circular Economy

Refurbishment plays a crucial role in CE by promoting sustainability, resource conservation, and waste reduction goals. It can be integrated into several aspects of product design, business models, and consumer behaviour to suport a circular and sustainable economy (Bocken *et al*., 2016; Kirchherr *et al*., 2017; Hernandez, 2019).

Product Restoration

Refurbishment involves repairing and rejuvenating products such as electronics, appliances, furniture, and machinery to restore their functionality and aesthetical appeal (Tukker & Tischner, 2006; Bakker *et al*., 2014; Geissdoerfer *et al*., 2017; Hernandez, 2019). This process includes repairing damaged components, replacing worn-out parts, and refinishing surfaces. By extending product lifespans, refurbishment reduces the need for new replacements, conserves resources, and minimises waste, contributing to a more sustainable use of materials and energy. Refurbished products are often a cost-effective alternative to new purchases, offering consumers access to high-quality, reliable items at a fraction of the cost. CE promotes lower environmental impact, reduced waste generation, and decreased greenhouse gas emissions associated with the production of new goods. Refurbishment aligns with circular business models such as remanufacturing and rental services, fostering a closed-loop system, where products are reused and rejuvenated.

Component Replacement

In certain cases, refurbishment may include replacing worn or outdated components with new or improved ones, ensuring optimal product performance and efficiency (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017). Identifying and replacing obsolete parts enhances the functionality of refurbished products, allowing them to meet or exceed their original specifications. By selectively replacing components rather than manufacturing entirely new products, refurbishment reduces overall resource consumption. Additionally, upgrading products with more sustainable components—such as energy-efficient motors or LEDs—can lower environmental impact and improve energy efficiency. Component replacement makes refurbished products competitive with new ones in terms of performance and cost, reducing demand for new products while offering economic savings and environmental benefits.

Quality Assurance

Refurbished products often undergo rigorous quality control processes to ensure they meet or exceed original specifications, helping to build consumer trust (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Alivojvodic & Kokalj, 2024). These include thorough inspections, evaluations, and verification to ensure refurbished products function as well as, or better than, new ones. Some refurbished items receive certifications, such as “Certified Refurbished”, indicating that they have passed stringent quality checks and meet established performance standards. Performance testing covers key components and features to guarantee smooth and efficient operation. Additionally, aesthetic aspects such as cosmetic condition are assessed to ensure the product appears as good as new. By maintaining high-quality standards, refurbishment enhances consumer confidence, ensuring reliability and warranty-backed assurance for refurbished goods.

Sustainability

Refurbishment supports sustainability by reducing the need to manufacture new products, conserving resources, and minimising waste disposal in landfills or incineration (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Alivojvodic & Kokalj, 2024). This aligns with waste minimisation goals in sustainable practices. Because the energy and raw material inputs associated with manufacturing new products are significantly higher than those required for refurbishment, refurbishment reduces the environmental footprints of consumer goods and contributes to reduced greenhouse gas emissions associated with manufacturing. Refurbishment aligns with circular business models that promote a closed-loop system, reducing reliance on the linear “take-make-waste” approach (Mansor *et al*., 2023).

Economic Opportunities

The refurbishment industry creates economic opportunities by generating jobs in repair, refurbishment, and quality control while supporting the growth of the secondary market for refurbished goods (Tukker & Tischner, 2006; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019; Ellen MacArthur Foundation, 2019). Employment opportunities arise across different stages of refurbishment, including roles for technicians, repair specialists, quality control personnel, and logistics experts. Local repair shops and refurbishment centres further contribute to the economic vitality of communities by providing jobs and supporting small businesses. The secondary market for refurbished goods offers consumers access to affordable, high-quality products while reducing the demand for new manufacturing. The refurbishment sector can thus foster entrepreneurship and innovation by extending product lifespans and improving refurbishment processes. Selling refurbished products at lower prices than new ones helps consumers save money, increasing disposable income.

Refurbishment in CE involves renovating or restoring products, components, or assets to a like-new or improved condition, extending their useful life and reducing waste. This aligns with resource conservation, waste reduction, and sustainable consumption.

Reduced Material in the Circular Economy

Reduced material in CE refers to minimising the use of virgin or new materials in product design and manufacturing. Strategies such as material efficiency, lightweighting, and dematerialisation help reduce overall resource demand (Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Korhonen *et al*., 2018; Hernandez, 2019).

Material Efficiency

Material efficiency involves using fewer materials to generate a product or achieve the same functionality through improved design, advanced manufacturing techniques, and waste reduction during production (Tukker & Tischner, 2006; Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Alivojvodic & Kokalj, 2024). This approach optimises the use of natural resources by reducing the number of raw materials required to generate a product or provide a service. Improved product design and engineering can achieve material efficiency. Designing products requiring fewer materials but maintaining or enhancing functionality is a key objective. Advanced manufacturing techniques such as lean manufacturing and just-in-time production can eliminate waste and minimise material usage during manufacturing. Material efficiency aligns with the principles of CE by extending product lifespans and reducing the requirement for new material extraction. It also contributes to reduced environmental impact by conserving resources, lowering energy consumption, and minimising waste generation.

Lightweighting

Lightweighting involves designing products with reduced weight without compromising on performance or safety, leading to reduced material consumption and lower energy requirements during use (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019; Alivojvodic & Kokalj, 2024). This strategy optimises material use by reducing overall product weight while maintaining or improving its functionality and safety. Lightweighting contributes to resource efficiency and minimises the environmental impact associated with material extraction and production as the process uses less material to achieve the same performance. Additionally, lighter products often require less energy to operate, whether in transportation, industrial applications, or daily use, lowering both energy consumption and greenhouse gas emissions. This approach is particularly relevant in the automotive and aerospace industries, where lighter vehicles and aircraft require less fuel, resulting in cost savings and reduced carbon emissions. Lightweighting aligns with the principles of CE by extending the life of products and promoting sustainability through responsible resource management.

Dematerialisation

Dematerialisation refers to reducing material intensity in products and services by shifting from physical goods to digital alternatives or substituting physical goods with services where possible (Tukker & Tischner, 2006; Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Hernandez, 2019).

This approach reduces the amount of physical materials needed to produce goods or deliver services, ultimately lowering resource consumption and waste generation. In several cases, dematerialisation involves the digitisation of products, processes, and services; this transition from physical to digital can significantly reduce material usage. Furthermore, dematerialisation can be achieved by providing services instead of physical products. For example, streaming services eliminate the need for physical DVDs, reducing resource demand. Fewer materials can be used to meet consumer needs; dematerialisation supports resource efficiency and minimises environmental impacts associated with material extraction, production, and disposal. It aligns with the principles of CE by extending the life of products and promoting sustainability through responsible resource management.

Resource Conservation

Reduced material consumption plays a crucial role in resource conservation by preserving natural resources, minimising waste generation, and lowering the environmental impact of production and consumption (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Alivojvodic & Kokalj, 2024). By using fewer raw materials to generate goods and services, industries can mitigate the depletion of finite natural resources while generating less waste throughout the entire product lifecycle, from manufacturing to disposal. Reduced material consumption generates lower environmental footprints, including reduced energy usage, greenhouse gas emissions, and pollution associated with resource extraction and production. It aligns with the principles of CE by emphasising responsible resource management and extended product lifespans. Reduced material consumption supports sustainability by fostering responsible and less resource intensive consumption patterns.

Circular Material Flow

In CE, materials should flow efficiently through cycles of use, recovery, and recycling, reducing the need for continuous extraction of new resources (Ellen MacArthur Foundation, 2013; Bocken *et al*., 2016; Geissdoerfer *et al*., 2017; Alivojvodic & Kokalj, 2024). A CE prioritises resource efficiency by keeping materials and products in use for as long as possible through recycling, refurbishment, and other circular practices. It establishes closed-loop systems that continuously reuse, recycle, remanufacture, or reduce the demand for virgin resources. By decreasing resource extraction and minimising waste, a CE helps lower environmental impacts, including reduced energy consumption and greenhouse gas emissions. This approach supports responsible and sustainable material management, ensuring that resources are used efficiently and their lifecycle impacts are minimised. Additionally, circular practices can create economic opportunities in recycling, remanufacturing, and other related sectors, generating jobs and driving economic growth.

The concept of reduced material in CE contributes to sustainability, resource conservation, and waste reduction goals. It provides valuable insights into how material efficiency, lightweight, and dematerialisation can be integrated into different aspects. However, despite its advantages, reduced material consumption faces challenges related to product performance, consumer acceptance, and regulatory barriers, as depicted in Figure 1.

Challenges and Perspectives

The key principles of a circular and sustainable economy emphasise responsible resource management and environmental conservation. However, several challenges must be addressed to realise these principles effectively (European Commission, 2020; Ellen MacArthur Foundation, 2022).

Resource Efficiency

Efficient use of resources is crucial to minimise waste and maximise the value derived from resources throughout their lifecycle. However, technological limitations in recycling and reprocessing pose challenges. Additionally, innovative business models are needed to incentivise resource efficiency.

Closed-loop Systems

Creating closed-loop systems, where products, materials, and resources are reused, repaired, or recycled helps reduce dependency on finite resources and minimises environmental impact. However, achieving this requires standardised recycling processes, infrastructure investments, and shifts in consumer behaviour.

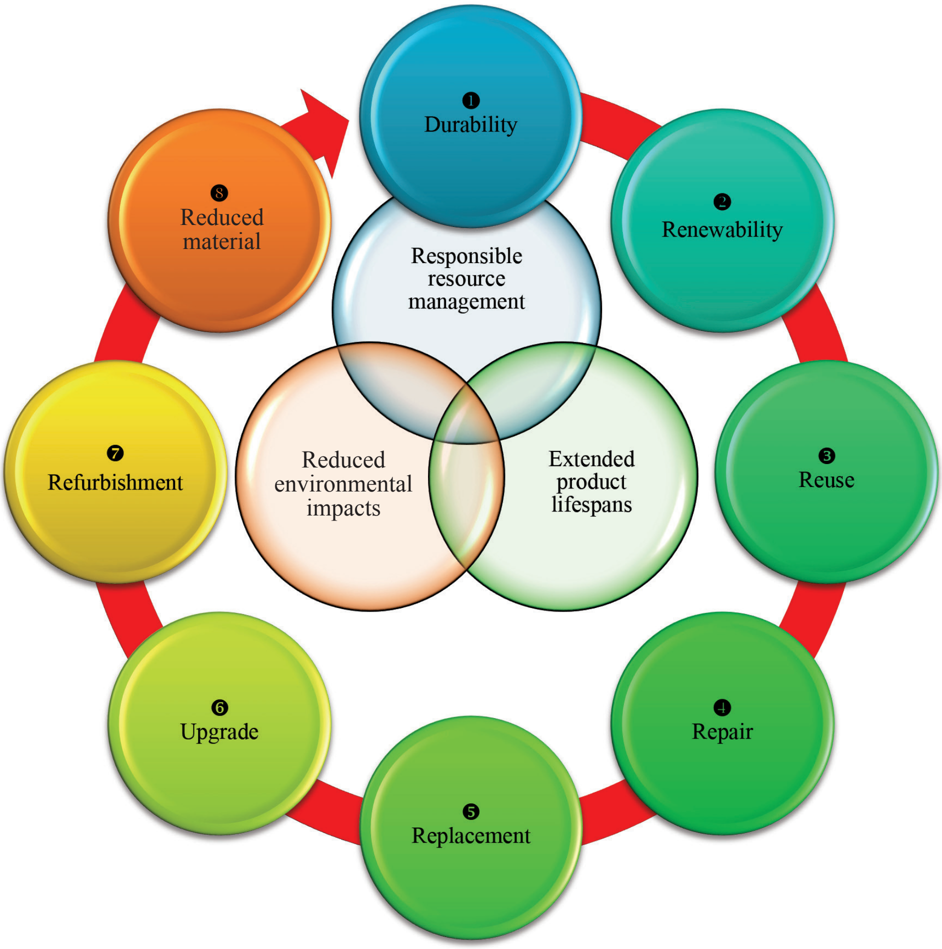

Figure 1: Key principles of a circular and sustainable economy, emphasising responsible resource management and environmental conservation

Design for Environment

Sustainable product design involves using eco-friendly materials and ensuring ease of disassembly for recycling or reuse. Challenges include balancing design aesthetics and functionality with environmental considerations, as well as educating designers and manufacturers on sustainable design principles.

Policy and Regulation

Effective policies and regulations are crucial for promoting a circular economy. However, coordinating policies across different sectors and regions remains complex. Ensuring compliance, enforcement, and adaptability to evolving technologies and business models also presents significant challenges.

Consumer Behaviour

Encouraging sustainable consumption habits is key to the success of a circular economy. Challenges include raising awareness about the environmental impact of consumption choices, overcoming consumer preferences for new products over reused or repaired ones, and incentivising sustainable purchasing decisions.

Business Models and Collaboration

Developing business models that prioritise sustainability such as product as a service or sharing platforms can drive CE forward. Challenges include transitioning from traditional linear business models, fostering collaboration among stakeholders across supply chains, and ensuring profitability while integrating sustainability principles.

Technological Innovation

Emerging technologies such as the Internet of Things, artificial intelligence, and advanced recycling technologies, are essential for optimising resource use and enabling circular practices. Challenges include the high costs of implementing new technologies, scalability issues, and ensuring that technological solutions are environmentally beneficial throughout their lifecycle.

A circular and sustainable economy hinges on responsible resource management and environmental conservation. However, challenges such as technological constraints, lack of standardised recycling processes, policy coordination, and consumer resistance must be addressed. Developing sustainable business models and integrating advanced technologies are essential but require overcoming cost and scalability barriers. Successfully implementing these principles will necessitate collective efforts from policymakers, businesses, and consumers to create a truly sustainable economy.

Discussion

Efficient resource allocation and strategies to prevent resource depletion are central to sustainability. One key approach is to mimic natural cycles, ensuring resource regeneration while promoting responsible management and innovation. This approach acknowledges the finite nature of resources and seeks to extend product lifespans through reuse, thereby minimising waste, conserving resources, and shifting society away from a disposable culture (Colombo *et al*., 2021; Thummakun *et al*., 2023). Repair is a crucial sustainability practice, as it conserves resources and reduces waste, contributing to a more sustainable product lifecycle. In a circular economy, emphasis is placed on designing eco-friendly, durable, and long-lasting products to reduce waste and encourage responsible consumption (Khan *et al*., 2022; Sarkis, 2023; Valeepitakdej *et al*., 2023). Technological and design advancements also play a significant role by improving product performance and extending their lifespan, which in turn lowers environmental impact (Khan *et al*., 2022). Renovating products or assets to restore them to near-original condition conserves resource and aligns with sustainable consumption by reducing the need for new raw materials. Moreover, using fewer materials while maintaining the same level of functionality is an efficient approach to conserving resources and reducing waste (Rejeb *et al*., 2023). Supporting a circular economy involves not only implementing these practices, but also advocating for relevant policies, raising awareness, and integrating these principles into daily life (Mahasinpaisarn, 2019). Key principles include durability, renewability, reuse, repair, replacement, upgrade, refurbishment, and reduced material usage (Koval *et al*., 2023). These strategies contribute to a more environmentally friendly and sustainable world by optimising resource use and minimising environmental harm.

Conclusions

A circular and sustainable economy emphasises responsible resource management, extended product lifespans, and reduced environmental impacts. The "7R-U-D" framework encapsulates key principles that contribute to sustainability. Renewability involves mimicking natural cycles for resource regeneration, acknowledging their finite nature and promoting responsible management. Reuse extends product lifespans through sustainable practices, minimising waste, and conserving resources while shifting away from a disposable culture. Repair plays a vital role in sustainability by extending the lifespan of products, contributing to a more circular and sustainable economy through waste reduction. Replacement entails selecting products with lower environmental impacts or longer lifespans, which reduces waste generation and encourages responsible consumption. Refurbishment restores product to near-original condition, extending their useful life which promotes resource conservation and sustainable consumption. Reduced material use emphasises material efficiency, lightweighting, and dematerialisation, ensuring that fewer materials are used while maintaining functionality, thus, contributing to resource conservation and a lower environmental impact. Upgrading products through novel technologies or design features improves performance and longevity, reducing environmental impact while extending product lifespans. Durability prioritises environmental preservation by ensuring resilience and sustainability and efficiently allocating resources to prevent depletion and harm while supporting growth. Table 1 shows related abbreviations, nomenclatures, and symbols used in this article.

Recommendations

Theoretical Implications

The study of key circular economy principles emphasises closing resource loops, fostering reuse, and minimising waste. It challenges traditional growth models by integrating ecological principles with economic efficiency, supporting sustainable development. The research highlights decoupling economic growth from resource depletion and environmental degradation, promoting long-term ecological resilience.

Practical Implications

The study provides actionable insights for businesses to optimise resource use, innovate circular models, and reduce costs. Policymakers are encouraged to promote resource efficiency through supportive policies. It advocates for responsible consumption, emphasising durability and recycling, while urging educational institutions to integrate CE principles into curricula for broader societal impact.

Limitations of the Study

The study may not fully account for deep-rooted consumer behaviours and cultural resistance to transitioning away from ownership-based consumption to models such as product-as-a-service or sharing economies. These behavioural challenges pose significant barriers to widespread adoption.

Future Research Direction

Future research should focus on long-term studies measuring the environmental, social, and economic impacts of CE practices to assess their sustainability. Additionally, further exploration is needed to address behavioural and cultural resistance through interdisciplinary approaches. Additionally, research is needed on aligning international policy frameworks and harmonising trade, regulatory, and environmental policies globally.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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Appendices

Table 1: Abbreviations, nomenclatures, and symbols

Abbreviations, Nomenclatures, and Symbols	The Meaning of the Abbreviations, Nomenclatures, and Symbols
CE	Circular economy, an economic system aimed at eliminating waste and promoting the continual use of resources.
Big Data	Vast, high-velocity, diverse data analysed to uncover patterns and drive strategic initiatives.
IoT	The Internet of Things, a network of physical objects with sensors and software that exchange data over the Internet.
AI	Artificial intelligence, the simulation of human intelligence in machines programmed to think and learn like humans.
Blockchain	A technology that stores distributed, tamper-resistant data by linking each record in a chain known as a block.
CBE	Circular bioeconomy, which integrates circular economy with bio-based resources, focusing on sustainability and reduced environmental impact.
DIY	Do-it-yourself, referring to activities where individuals undertake tasks or projects independently without professional assistance.
E-waste	Electronic waste, referring to discarded electronics such as computers, mobile phones, and appliances that are obsolete or no longer used.
HVAC	Heating, ventilation and air conditioning, a climate control system that regulates temperature, humidity, cleanliness, and air distribution.
LED	Light-emitting diode, a semiconductor device that emits light efficiently when an electric current passes through it.
DVD	Digital versatile disc, an optical disc used as a data storage medium that records various types of data using light.
SDGs	Sustainable Development Goals.