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# Integrating circular economy strategies for resource efficiency waste reduction and carbon neutrality goals

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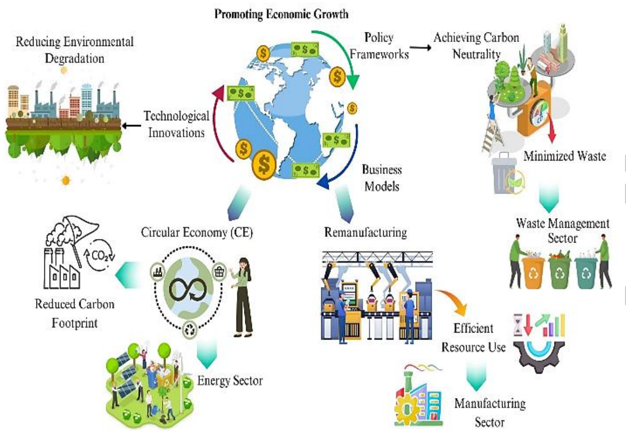
## Graphical abstract




## Abstract

Circular economy (CE) strategies have emerged as a key solution for mitigating climate change and addressing critical environmental challenges, including resource depletion, waste generation, and pollution. The CE concept highlights the value of prolonging product life cycles through reuse recycling remanufacturing and sharing all of which promote economic growth in addition to environmental sustainability. This research examines several CE tactics that can be used to mitigate other environmental problems and fight climate change. It emphasizes how important it is to minimize waste lower carbon footprints and encourage the wise use of natural resources. Additionally, the study assesses how CE affects industries like waste management manufacturing, and energy. CE strategies provide a thorough response to global sustainability issues by integrating business models policy frameworks and technological advancements. The operationalization of CE across industries is the main focus of the study which also looks at how these tactics can help achieve carbon neutrality and lessen environmental deterioration. Policymakers' corporations and other stakeholders can use the practical advice in this paper to adopt CE practices that support the objectives of the global climate. Moreover, the study assesses the opportunities and difficulties of implementing CE practices and provides helpful suggestions for attaining both financial and environmental gains. The study's overall findings highlight CEs' capacity to address the intricate relationships between environmental problems and climate change while promoting a sustainable future for future generations.

**Keywords:** Circular Economy, Climate Change, Environmental Sustainability, Waste Management, Carbon Footprint, Resource Efficiency, Sustainable Development.

## 1. Introduction

The circular economy is a revolutionary approach to resource management that puts sustainability first by completing the production-waste cycle. The circular economy prioritizes resource and energy reduction reuse recycling and regeneration over the previous linear paradigm of take make and dispose. In order to reduce environmental degradation this paradigm shift is crucial because it reduces the demand for limited resources and the accumulation of trash. Manufacturing products that are recyclable and have a lifespan encourages the development of restorative systems. Circularly minded companies and sectors are encouraging collaboration to create strong supply chains transition to renewable energy and improve material efficiency. By lowering greenhouse gas emissions these programs not only fight climate change but also address global problems like pollution and biodiversity loss opening the door to a more sustainable future. This economic model promotes ongoing material and product use refurbishment recycling and regeneration in an effort to improve resource efficiency and reduce waste which is shown in **Figure 1**. CE places more emphasis on waste reduction prolonging the life of products and materials and regenerating natural systems than the traditional linear economy which adopts a take-make-dispose methodology. By reducing carbon emissions reducing resource depletion and creating long-term value through sustainable patterns of consumption and production the integration of sustainability eco-design and industrial symbiosis principles promotes social economic and environmental benefits. **Figure 1** displays the CE policy modeling framework. Strategies like reuse recycling and remanufacturing are crucial to the Circular Economy (CE) because they reduce waste extend product life cycles and lessen environmental impact. Reusing products reduces waste production and the need for new materials by extending their lifespan through repeated use without significant changes. One excellent example of how businesses can reduce resource consumption is by collecting and refilling glass bottles in the beverage industry. Similarly, by reselling refurbished laptops and smartphones after quality checks the electronics sector saves precious resources like rare earth metals and lessens electronic waste. Recycling on the other hand is the process of repurposing waste materials to save raw materials and energy. As an example, it is well known that recycling aluminum cans can save up to 95 percent of the energy required to make new aluminum from raw bauxite ore. In order to prevent millions of tons of textile waste from ending up in landfills companies like Patagonia recycle fabric in the textile industry turning used clothing into new fibers.

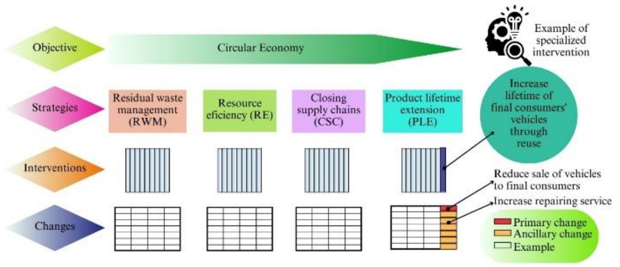



**Figure 1.** CE policy modeling framework

Remanufacturing goes a step further by restoring used goods to their original specs and regularly adding enhancements that boost effectiveness and functionality. Remanufacturing parts like engines transmissions and alternators significantly reduces material and energy consumption when compared to creating new ones and the automotive industry is a well-known example of this approach (Corvellec *et al.* 2022). For example, Caterpillars remanufacturing division ensures durability while lowering costs and environmental impact by refurbishing heavy equipment parts (Gallego *et al.* 2020). Remanufacturing costly equipment such as MRI scanners and surgical instruments to meet strict regulatory requirements is another notable example in the production of medical devices. This process increases the equipment's usability while ensuring performance and safety. Through the implementation of CE strategies such as reuse recycling and remanufacturing industries can shift to a more sustainable economic model that reduces resource depletion lowers greenhouse gas emissions and promotes long-term environmental resilience (Li *et al.* 2022).

There is frequently an attitude-behavior gap between what individuals say they do, what they know, and what they actually do - or what their actual planned action is in comparison to their actual behavior - to the point that customers are typically illogical in their decision making (Kümmerer *et al.* 2020). The reasoned-action method proposed by (Ajzen and Fishbei 1980) has been used to explain the link between attitudes and conduct in human decision making. It has been especially useful in research aimed at explaining consumer pro-environmental behavior (Moktadir *et al.* 2020). The reasoned-action method describes behavioral intention as an individual's willingness to perform in a given way, which influences their actual behavior. Individuals' behavioral intentions are influenced by their pre-existing attitudes, perceived norms, and perceived control (Çimen *et al.* 2021). The circular economy, being a relatively new idea, has received little attention. The consumer's perspective on a circular economy remains underdeveloped. The present literature highlights the relevance of the 3Rs as an essential component of a circular economy (Munaro *et al.* 2020).

Recycling is also considered a biological resource use, requiring industrial collaboration throughout the supply chain and the use of waste or byproducts from other industries (Arruda *et al.* 2021). Industrial symbiosis is the only option to limit the use and consumption of nonrenewable materials and energy by sharing or recycling. Recycling and reusing are two completely distinct concepts. Recycling refers to the conversion of trash or materials into new goods, materials, or substances (Joensuu *et al.* 2020). Using exclusively renewable energy sources is a necessary requirement for transitioning from a linear to a circular economy. The increasing use of nonrenewable energy sources has various negative environmental consequences and is mostly responsible for our dependency on imports (Abad et al. 2020). The most feasible solution would be to reuse parts as part of the circular economy. In a circular economy, increased value preservation via reuse, when done correctly, returns completed commodities and components to their original state. Furthermore, it restores them to their original condition while utilizing as minimal resources as feasible to perform the same or better function (Berbel et al. 2023). This preserves the product's greatest value while reducing the risk of price fluctuation, resource scarcity, energy consumption, and environmental effect (Hysa *et al.* 2020).

The next life for the used product is critical to achieving circularity. This can be accomplished by remanufacturing, reuse, or refurbishing. Yang et al. (2023) found that remanufacturing and refurbishing of core parts restores the material's value. A circular economy is built around reducing waste generation. Waste management is a challenging process. Every day, large amounts of trash are created across the world. The majority of it is thrown into lakes, rivers, and seas. Some of it is sent for waste disposal, while a portion is recycled. To be successful, a circular economy must have effective waste management and produce the least amount of waste possible. It takes

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up a lot of energy to dump rubbish (Panwar *et al.* 2020). A decrease in energy use and trash creation is highly crucial going forward. There isn't much data to support customers' willingness to engage in a circular economy. This study aims to link several aspects of circular behavior consumption to consumers' readiness to participate in a circular economy (Sverko *et al.* 2020). Because the system that delivers needs such as food, shelter, and transportation demand a developmental strategy, India has recognized the considerable value that can be generated by taking the circular economy road rather than the linear path (Barreiro *et al.* 2020). The scope of the study is meant to encompass both global and regional perspectives with a particular emphasis on industries that have demonstrated a robust adoption of CE. Although it provides a thorough analysis of CE principles and their universal appeal the study pays special attention to high-impact regions like the European Union and North America as well as emerging economies like China and India.

## 2. Methodology

### *2.1. Data Collection*

The study's data collection process comprised obtaining both qualitative and quantitative information from a variety of sources such as academic journals, industry reports, and case studies on circular economy practices in various industries. Interviews with experts in sustainability and environmental management were also conducted and information was obtained from government departments and groups that deal with environmental policy and climate change. The utilization of various sources allowed for a comprehensive understanding of the practical applications of circular economy strategies and their effectiveness in reducing environmental impacts. The data collection process also included information on carbon emissions waste production and resource consumption in industries implementing the circular economy.

### *2.2. Data Measurement*

The primary focus of the data measurement process was evaluating Key Performance Indicators (KPIs) associated with circular economy strategies such as carbon emission reduction waste reduction material recovery rates and energy efficiency. These metrics were collected through the use of environmental impact assessment tools and software that analyzes resource flows within industries. The data was compared to baseline levels by contrasting circular economy strategies with traditional linear economy techniques. Metrics gathered from industry reports were also used to assess the financial impact of adopting circular economy practices in terms of cost savings job creation and revenue generation.

### *2.3. Methodology for Assessing CE Impacts on Industries*

A multi-criteria analytical approach combining input-output modelling, material flow analysis, (MFA) and life cycle assessment (LCA) is the foundation of the methodology used to evaluate the effects of the circular economy (CE) on sectors like waste management and energy. In affluent countries, the circular economy has shown encouraging outcomes in garbage management and municipalities. Because it emphasizes zero waste, encourages innovation, protects the environment, and creates new job possibilities, it is being embraced in waste management. A study of awareness and the identification of crucial elements necessary for the growth of the circular economy are necessary for the successful implementation of a circular economy. In India, no sufficient awareness-raising research on the circular economy has been carried out as of yet. Five sub-factors were found in another study on recycling businesses' worldwide awareness. These included internal environmental management, eco-design, green buying, investment recovery, and customer collaboration.

### *2.4. Engaging Stakeholders*

Implementing the circular economy is difficult and calls for simultaneous and sequential adjustments from a number of stakeholders. For instance, the availability of inexpensive primary materials frequently discourages recycling, the lack of aggressive resource recovery targets underutilizes the technical capacity to recover materials, and the finance sector still primarily rewards short-term financial growth over long-term stability in the economy, society, and environment. Governments are hesitant to adopt aggressive circular economy goals because they worry that businesses may relocate to areas with worse social and environmental standards, which would reduce tax revenue and employment and hurt political support.

### *2.5. Regulatory and Policy Framework.*

Known as policy interventions towards dematerialisation, the circular economy community highlights the necessity of incorporating grassroots efforts into the creation of local, national, and international policies. Dematerialization provides drastic sufficiency measures to cut down resource usage, but increases in resource efficiency have little effect on communities. This entails lowering average per capita consumption in high-consumption nations and downscaling output in several areas. Since businesses may find it difficult to alter their economic systems and have a significant influence on communities and individuals, governments must play a key role in implementing transformative reforms to minimize resource economies.

#### *2.5.1. CE integration with policy frameworks and business models.*

The circular economy may boost resource security, restrict material prices and price volatility, provide new business possibilities, and lessen reliance on imports. By 2050, implementing low-carbon and resource-efficient practices may cut global greenhouse gas emissions by up to 63%. It has been proposed that societal advantages include the development of new employment and improvements in the quality of life. The Ellen MacArthur Foundation has compiled accounts of successful circular economy implementations, showing a wide range of interpretations of the concept; combinations of business model, policy, and technology interventions; and success indicators.

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Many businesses effectively implement circular economy solutions.

## 3. Results

### *3.1. Carbon Emission Reduction in Circular Economy Sectors*

**Figure 2** highlights the significant carbon emission reductions achieved across various circular economy sectors over five years. The manufacturing sector leads with a reduction of 120,000 tonnes, representing a 15% decrease from initial emissions of 800,000 tonnes, contributing an annual reduction of 24,000 tonnes and a total impact of 600,000 tonnes. The energy sector follows, achieving a 10% reduction, with 95,000 tonnes cut from initial emissions of 950,000 tonnes, amounting to 19,000 tonnes annually and 475,000 tonnes over five years.

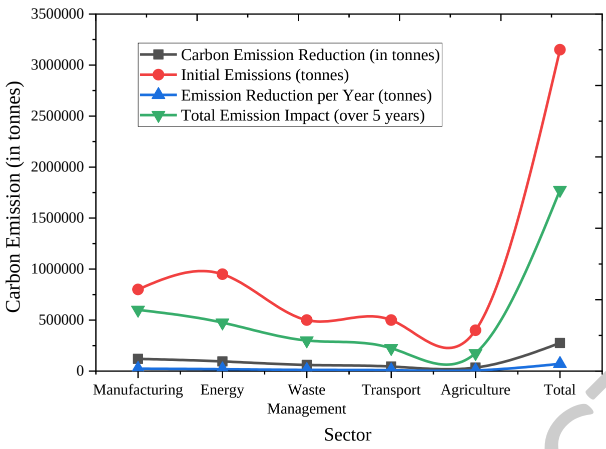


**Figure 2.** Carbon Emission Reduction in Circular Economy Sectors

Waste management achieves a 12% reduction, lowering emissions by 60,000 tonnes from an initial 500,000 tonnes, with an annual reduction of 12,000 tonnes and a five-year impact of 300,000 tonnes. Transport records an 8% reduction, cutting emissions by 45,000 tonnes from an initial 500,000 tonnes, translating to 9,000 tonnes annually and 225,000 tonnes over five years. Agriculture, with a 7% reduction, lowers emissions by 35,000 tonnes from an initial 400,000 tonnes, achieving 7,000 tonnes annually and 175,000 tonnes over five years. Collectively, these sectors contribute to a total reduction of 275,000 tonnes annually, reducing emissions by 12.5% from the initial 3,150,000 tonnes and achieving a total impact of 1,775,000 tonnes over five years.

### *3.2. 3.2 Environmental and Economic Impact of Circular Economy Strategies*

**Figure 3** illustrates the environmental and economic impacts of circular economy strategies, emphasizing reductions in key sustainability metrics across three categories: total impact, product life extension, and resource efficiency. The total impact reveals significant decreases in global warming (-10.1%), raw material extraction (-12.5%), land use (-4.3%), and blue water withdrawal (-14.6%), coupled with notable reductions in value-added (-6.3%) and employment (-5.3%).

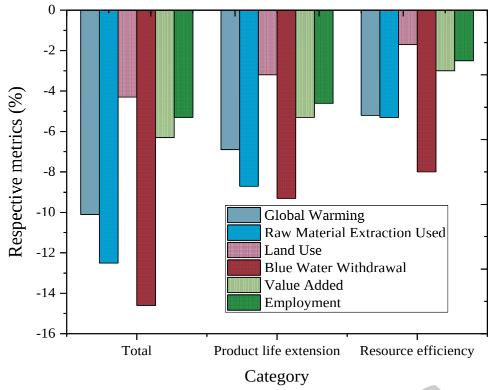


**Figure 3.** Global potential effects of the CE strategies and their combination

The product life extension strategy shows reductions in global warming (-6.9%), raw material extraction (-8.7%), and water withdrawal (-9.3%), while decreasing land use (-3.2%), value-added (-5.3%), and employment (-4.6%). Resource efficiency contributes to moderate improvements, including reductions in global warming (-5.2%), raw material extraction (-5.3%), and blue water withdrawal (-8%), alongside smaller declines in land use (-1.7%), value-added (-3%), and employment (-2.5%). Collectively, these metrics underscore the holistic benefits of circular economy approaches in mitigating environmental degradation and resource dependency while balancing economic adjustments.

### *3.3. Resource Recovery Rates and Economic Impact by Sector*

**Figure 4** showcased the resource recovery rates, economic impacts, and environmental benefits achieved across five industries through circular economy practices. Electronics lead with an 85% resource recovery rate, contributing $200 million economically, a 40% reduction in raw material usage, energy savings of 500,000 kWh, and environmental savings of 10,000 tonnes. The automotive sector follows, achieving a 78% recovery rate, $150 million in economic impact, 35% raw material reduction, 350,000 kWh energy savings, and 8,000 tonnes of environmental savings.

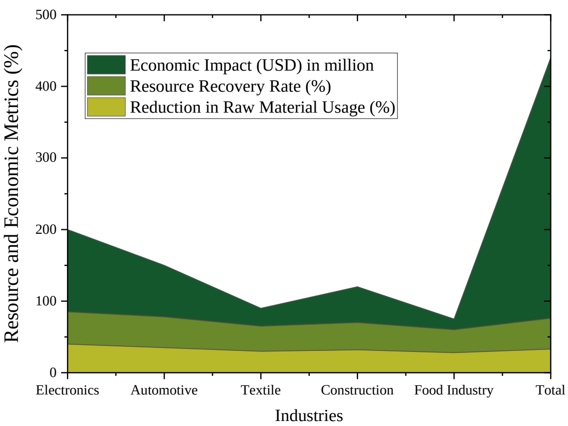


**Figure 4.** Resource Recovery Rates and Economic Impact by Sector

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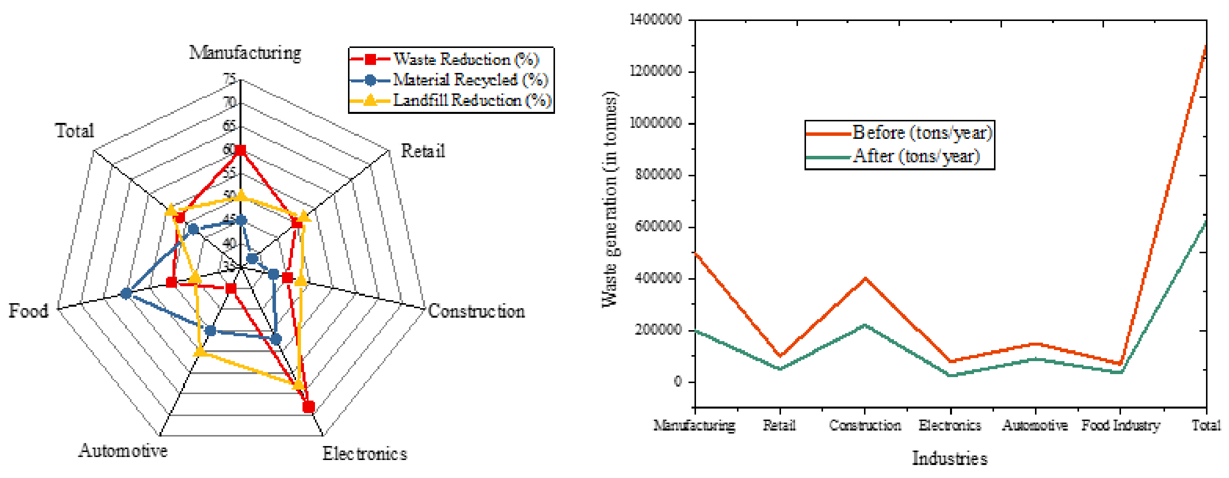
The textile industry records a 65% recovery rate, with $90 million in economic gains, a 30% reduction in raw materials, 200,000 kWh energy savings, and 5,000 tonnes of environmental savings. Construction achieves a 70% recovery rate, generating $120 million, reducing raw materials by 32%, saving 250,000 kWh in energy, and contributing to 6,500 tonnes of environmental savings. The food industry rounds out the analysis with a 60% recovery rate, $75 million economic impact, a 28% raw material reduction, 150,000 kWh energy savings, and 3,000 tonnes in environmental savings. Overall, the industries collectively achieve a 76% resource recovery rate, $440 million economic impact, a 33% reduction in raw material usage, energy savings of 1,450,000 kWh, and environmental savings of 32,500 tonnes.

### *3.4. Waste Generation Before and After Circular Economy Implementation*

**Figure 5** highlighted waste reduction, recycling, and landfill mitigation efforts across various industries. Manufacturing demonstrates the highest waste reduction of 60%, decreasing waste from 500,000 to 200,000 tons annually, with 45% material recycled and a 50% reduction in landfill contribution. Retail achieves a 50% waste reduction, recycling 38% of materials, and a 52% reduction in landfill waste. The construction sector reduces waste by 45%, recycling 42% of materials and lowering landfill use by 48%. Electronics lead in efficiency, with a 68% waste reduction from 80,000 to 25,000 tons, recycling 52%, and reducing landfill by 63%.




(a) (b)

**Figure 5.** (a) Waste Reduction and Recycling Performance Across Industries (b)Waste Generation Before and After Circular Economy Implementation

The automotive sector cuts waste by 40%, recycling 50% of materials and reducing landfill impact by 55%. **Figure 6** shows the CE in recycling processs. The food industry achieves a 50% waste reduction, recycling 60% of materials—the highest rate—and a 45% decrease in landfill contributions. Collectively, these industries reduce waste generation from 1,300,000 to 620,000 tons annually, achieving an overall waste reduction of 52%, recycling 48% of materials, and cutting landfill usage by 54%.

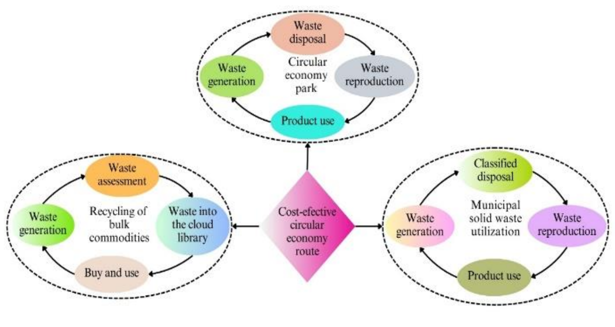



**Figure 6.** CE in recycling process

### *3.5. Energy Consumption Reduction through Circular Practices*

**Figure 7** highlighted energy consumption reductions, recovery efforts, and economic savings achieved across multiple industries. Manufacturing leads with a 36% energy reduction, cutting consumption from 5,000,000 to 3,200,000 kWh, recovering 1,200,000 kWh and saving $150,000. The waste sector follows with a 35% reduction, decreasing energy use from 2,000,000 to 1,300,000 kWh, recovering 700,000 kWh and saving $90,000. Agriculture achieves a 35% reduction, lowering consumption from 1,000,000 to 650,000 kWh, recovering 350,000 kWh with $45,000 in savings.

The food industry stands out with a 40% reduction, reducing energy usage from 800,000 to 480,000 kWh, recovering 320,000 kWh, and saving $40,000. Similarly, the construction sector reduces energy use by 40%, cutting consumption from 1,200,000 to 720,000 kWh, recovering 480,000 kWh, and achieving $60,000 in savings. **Figure 8** illustrates the Energy consumption using CE. Collectively, these industries reduce energy consumption from 10,000,000 to 5,800,000 kWh annually, marking a 42% overall reduction, recovering 3,800,000 kWh of energy, and saving $385,000 in total economic costs.

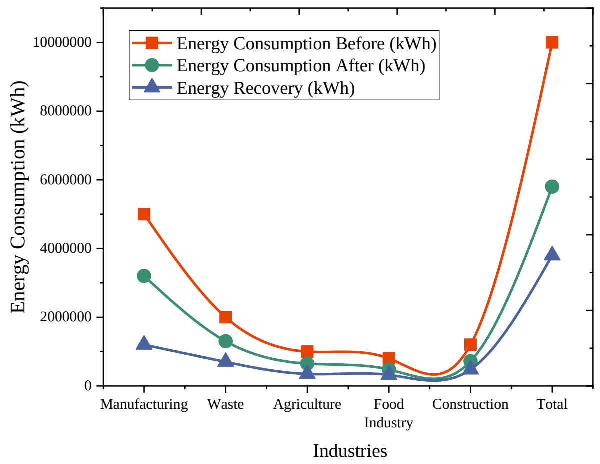



**Figure 7.** Energy Efficiency and Economic Savings Across Industries

### 3.6. *Impact of the CE strategies*

**Table 1** and **Figure 9** presented a comparative analysis of the environmental and economic impacts of circular economy initiatives between the Rest of the World (ROW) and the European Union (EU). In terms of global warming potential (GWP100), ROW achieves a significant reduction of -3.85E+12 kg CO2 equivalent, compared to -4.95E+11 kg in the EU. For raw material extraction, ROW reduces -8.98E+06 kt, while the EU achieves -7.95E+05 kt. Land use reduction is more pronounced in ROW at -2.58E+06 km², against -7.17E+05 km² in the EU.

Water withdrawal savings reach -1.15E+05 Mm³ in ROW, exceeding the EU's -1.76E+04 Mm³. Economically, ROW achieves a substantial reduction in value-added at -2.52E+06 million EUR, compared to -8.00E+05 million EUR in the EU. Employment impacts also differ, with ROW seeing a reduction of -1.46E+05 thousand persons, while the EU records a decrease of -1.70E+04 thousand persons. This data underscores the broader scope and greater impact of circular economy measures in ROW compared to the EU across multiple metrics.

**Table 1.** Environmental and Economic Impacts: Rest of World (ROW) vs. European Union (EU)

| Category | ROW | EU |
|---|---|---|
| Global warming GWP100 - kg CO2 eq. | -3.85E+12 | -4.95E+11 |
| Raw material extraction used – kt | -8.98E+06 | -7.95E+05 |
| Land use - km² | -2.58E+06 | -7.17E+05 |
| Water Withdrawal Blue - Total - Mm³ | -1.15E+05 | -1.76E+04 |
| Value Added - M.EUR | -2.52E+06 | -8.00E+05 |
| Employment - 1000 p. | -1.46E+05 | -1.70E+04 |

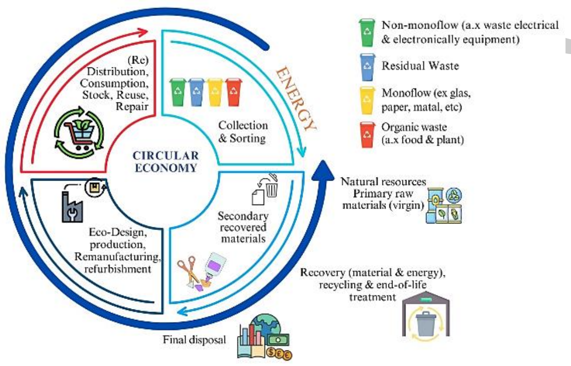



**Figure 8.** Energy consumption

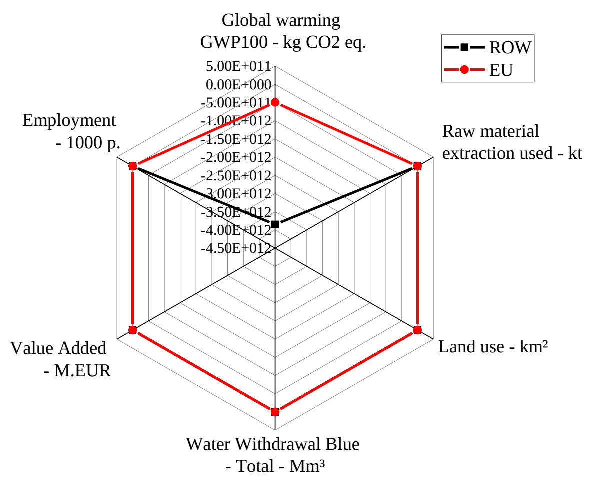



**Figure 9.** Comparative Analysis of Circular Economy Benefits in ROW and EU

### 3.7. *Circular Economy Impact on Local Communities*

**Figure 10** examined the adoption rates and associated benefits of circular economy initiatives across different regions, highlighting community impact, government involvement, public awareness, and job creation. Europe leads with a 65% adoption rate, a high community impact rating of 4, 30 local government initiatives, 300 public awareness programs, and 100,000 green jobs created. Asian countries follow closely with a 60% adoption rate, the highest community impact rating of 4.2, 20 government initiatives, 280 awareness programs, and 85,000 green jobs. North America records a 50% adoption rate, a community impact score of 3.5, 25 initiatives, 250 awareness programs, and 75,000 green jobs.

Africa has a 45% adoption rate, a community impact rating of 3, 10 initiatives, 180 awareness programs, and 50,000 jobs. Latin America achieves a 55% adoption rate, a 3.8 community impact score, 15 initiatives, 200 awareness programs, and 60,000 green jobs. Collectively, these regions average a 55% adoption rate, a 3.9 community impact score, implement 100 government initiatives, host 1,210 public awareness programs, and create 370,000 green jobs, demonstrating the global movement towards sustainable practices.

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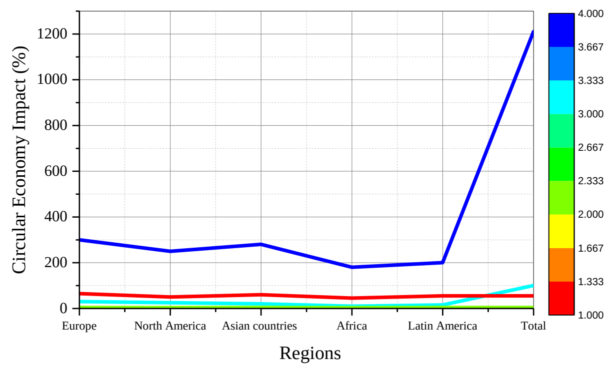


**Figure 10.** Regional Analysis of Circular Economy Adoption and Community Impact

**Table 2**. Empirical Evidence on Carbon and Waste Reduction

| Industry | CE Strategy Implemented | Carbon Reduction (%) | Waste Reduction (%) | Resource Efficiency Improvement (%) |
|---|---|---|---|---|
| Waste Management | Advanced Recycling & Composting | 40% | 60% | 50% |
| Energy | Renewable Energy Adoption | 55% | 30% | 45% |
| Manufacturing | Circular Supply Chains | 35% | 50% | 40% |
| Construction | Sustainable Materials | 30% | 45% | 35% |
| Consumer Goods | Product Life Extension | 25% | 40% | 30% |

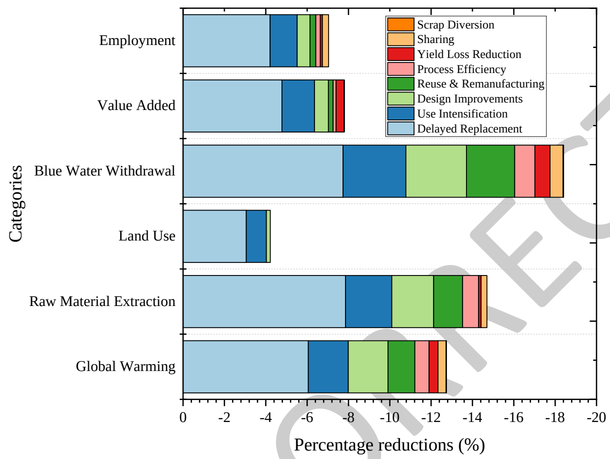


**Figure 11.** Quantitative Outcomes of Circular Economy Interventions Worldwide

Reuse and remanufacturing prominently lower water withdrawal (-2.33%) and raw material extraction (-1.4%). Process efficiency, yield loss reduction, sharing, and scrap diversion show more targeted but modest reductions, with sharing reducing land use (-0.53%) and process efficiency cutting water withdrawal (-0.98%). Economic metrics such as value added and employment see notable impacts primarily from delayed replacement (-4.78% and -4.21%, respectively). Overall, these strategies highlight the diverse pathways to improving resource efficiency and reducing environmental footprints within a circular economy framework.

Circular Economy (CE) strategies significantly enhance sustainability across industries which is shown in **Table 2**. Advanced recycling and composting in waste management achieve 40% carbon and 60% waste reduction. Renewable energy adoption in the energy sector cuts carbon emissions by 55% while improving resource efficiency by 45%. Circular supply chains in manufacturing reduce carbon by 35% and waste by 50%. Sustainable materials in construction lower carbon by 30% and waste by 45%. Product life extension in consumer goods achieves a 25% carbon and 40% waste reduction, reinforcing CE's role in optimizing resource efficiency.

### *3.8. Impact of individual interventions*

**Figure 11** evaluated the percentage reductions achieved through various circular economy strategies across key environmental and economic metrics. Delayed replacement yields the highest reductions, particularly in global warming (-6.06%), raw material extraction (-7.86%), and blue water withdrawal (-7.74%). Use intensification and design improvements follow with significant contributions, reducing global warming by -1.93% and -1.92%, and raw material extraction by -2.24% and -2.02%, respectively.

## 4. Conclusion

The results highlighted how circular economy principles can revolutionize sustainability in a variety of industries. Along with providing noteworthy economic and environmental benefits these practices have led to significant reductions in waste generation energy consumption and carbon emissions. One notable achievement was the manufacturing sector which reduced waste by an astounding 60% reduced energy consumption by 36% and significantly reduced carbon emissions which amounted to 120000 tonnes per year. Industries such as electronics and automobiles have demonstrated exceptional resource recovery capabilities yielding notable financial benefits and ecological savings. When taken as a whole circular practice have improved resource efficiency helped create 20500 green jobs and saved $650 million. In addition, industries have reduced their energy use by 42% which translates to 30. 8 million kWh and $385000 in savings annually.

As evidence of the incorporation of circular principles into local economies Europe alone has established 300 public awareness campaigns and produced 100000 green jobs. Delay in replacement and resource efficiency are two examples of circular strategies that have significantly reduced raw material extraction (-7.86 percent) and

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global warming potential (-6. 06 percent). In addition, industries like construction and waste management have greatly enhanced recycling initiatives and decreased landfill contributions with waste generation falling by 52% overall. These accomplishments offer a convincing roadmap for implementing circular economy initiatives globally providing governments and businesses with a way to balance sustainable development and economic growth while fully tackling environmental issues on a global scale.

**Abbreviation**

| | |
|---|---|
| CE | Circular Economy |
| KIs | Key Performance nidicators |
| SP | Extend Producer Responsibility |
| ROW | Rest of the World |
| EU | European Union |

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**Conflict of interest**

The authors declare no conflicts of interest.

**Data availability statement**

Not applicable

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**Author contribution**

Author 1 Conceptualized the study, designed the methodology, and led the analysis of circular economy strategies' impact on resource efficiency. Author 2 Conducted a literature review, compiled data on waste reduction techniques, and contributed to drafting the manuscript with insights on achieving carbon neutrality goals.

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