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Technology and Innovation Management for Circular Economy in Nigeria's Renewable Energy Sector

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Abstract

This research explores the role of technology and innovation management in facilitating the adoption of Circular Economy (CE) principles within Nigeria's renewable energy sector. As Nigeria strives to address its energy deficit through renewable energy technologies, the integration of CE practices remains limited, especially in terms of resource efficiency, waste reduction, and material recycling. Using a mixed-methods approach, including semi-structured interviews with key stakeholders and a survey of renewable energy firms, this study assesses the extent of technology adoption and Circular Economy integration. The results indicate that solar photovoltaics (PV) and biomass are the most widely adopted technologies, with 80% of firms using solar PV. However, advanced Circular Economy practices, such as waste-to-energy and material regeneration, have been adopted by only 40% of firms. The research identifies several key barriers to the adoption of Circular Economy practices, including technological limitations, high initial costs, lack of government support, and low awareness. The findings underscore the pivotal role of innovation management in overcoming these barriers, particularly through the adoption of advanced technologies like solar PV and energy storage systems. The study concludes by offering policy recommendations, including the need for financial incentives, investment in research and development, and fostering collaborative innovation. These measures are essential for accelerating the adoption of Circular Economy principles, ensuring the sustainability and growth of Nigeria's renewable energy sector.

Keywords: Circular Economy, Renewable Energy, Innovation Management, Technology Adoption, Nigeria

Introduction

Nigeria, as one of Africa's largest economies, is grappling with an energy crisis that hampers its economic development and growth. Despite being endowed with vast renewable energy resources, including solar, wind, and biomass, the country's energy sector remains largely reliant on fossil fuels, which contribute to greenhouse gas emissions and environmental degradation. As of 2020, over 80 million Nigerians had no access to electricity, and even those connected to the grid often face intermittent power supply. These challenges underline the critical need for sustainable energy solutions, with renewable energy being positioned as a viable alternative to address both environmental concerns and energy access gaps [1].

Technology has become a key driver of progress in renewable energy systems, playing a crucial role in optimizing energy generation, distribution, and consumption. Recent advancements, including the integration of smart grids, energy storage solutions, and decentralized energy systems, offer promising solutions to improve the efficiency and stability of Nigeria's energy sector. Moreover, the effective management of innovation within the renewable energy space is pivotal in ensuring the scalability and adoption of these technologies. However, Nigeria's renewable energy sector still faces significant challenges, including insufficient technological infrastructure, underdeveloped innovation management practices, and a lack of comprehensive policies supporting the adoption of cutting-edge technologies [2].

In this context, the integration of Circular Economy (CE) principles presents a unique opportunity to enhance the sustainability of renewable energy systems. The Circular Economy model, which emphasizes reducing, reusing, and recycling materials to create closed-loop systems, contrasts with the traditional linear economic model and aligns

with the global shift towards more sustainable practices. In the renewable energy sector, Circular Economy can offer solutions to resource inefficiency, waste management, and the extended lifecycle of energy infrastructure, thereby fostering long-term environmental and economic sustainability [3]. Despite its global importance, the adoption of Circular Economy practices in Nigeria's renewable energy sector remains limited, primarily due to technological, economic, and regulatory barriers. The transition to a Circular Economy in Nigeria's renewable energy sector requires a robust framework for technology and innovation management. Such a framework would ensure that emerging technologies are not only developed but also effectively deployed and scaled. Furthermore, it would provide the necessary infrastructure and strategic direction to facilitate the integration of Circular Economy practices, enabling Nigeria to tap into its renewable energy potential and achieve its sustainability goals.

Although Circular Economy principles have gained considerable attention globally, their practical application in the renewable energy sector of developing countries, particularly in Nigeria, remains underexplored. Nigeria's renewable energy sector is hindered by technological limitations, a lack of innovation management frameworks, and systemic inefficiencies that prevent the effective application of Circular Economy principles. Studies have shown that Nigeria's energy sector continues to face challenges such as underutilization of renewable resources, waste in energy production, and limited recycling of materials used in renewable energy technologies [4]. These issues suggest the need for a comprehensive approach to integrating technology and innovation management that can enable the country to transition to a more sustainable, circular energy system. This study aims to fill the gap by exploring how technology and innovation management can facilitate the adoption of Circular Economy principles in Nigeria's renewable energy sector. Specifically, the research seeks to examine the barriers to implementing these principles, identify the technological innovations that can drive Circular Economy practices, and propose actionable strategies for enhancing innovation management in the sector.

The primary objective of this research is to explore how technology and innovation management can support the transition to a Circular Economy within Nigeria's renewable energy sector. Specifically, this study aims to: (1) investigate the role of technology and innovation management in fostering the adoption of Circular Economy principles in the renewable energy sector, (2) identify the barriers hindering the widespread adoption of Circular Economy practices, including technological, economic, and regulatory challenges, and (3) propose strategies for enhancing the management of technology and innovation to facilitate the application of Circular Economy principles, thereby improving the sustainability and efficiency of renewable energy systems in Nigeria.

The adoption of Circular Economy practices in Nigeria's renewable energy sector is essential for improving sustainability, reducing waste, and optimizing resource use. The findings of this study will provide valuable insights into how technology and innovation management can drive the integration of Circular Economy principles, helping to unlock the potential for renewable energy to contribute more effectively to Nigeria's energy security and sustainability. By identifying key barriers and proposing strategic solutions, the research will contribute to the development of policies and practices that support the adoption of innovative technologies and sustainable practices in the renewable energy sector.

This research is significant not only for policymakers and industry stakeholders but also for academic researchers, as it offers a comprehensive examination of the intersection of technology, innovation management, and Circular Economy in the context of renewable energy in a developing economy. It will provide practical recommendations for

overcoming the systemic challenges currently limiting the sector's growth and help Nigeria transition towards a more sustainable, circular energy system. The insights generated from this study are expected to have far-reaching implications for the development of energy policies, investment in renewable energy technologies, and the creation of a sustainable business model that aligns with global sustainability goals. The findings will be particularly relevant to Nigeria's renewable energy sector, which is striving to overcome technological and financial barriers to achieve a more sustainable and circular energy future.

Methodology

Research Design

This study utilized a mixed-methods research design to comprehensively address the role of technology and innovation management in the adoption of Circular Economy (CE) principles within Nigeria's renewable energy sector. The mixed-methods approach was chosen to provide both a broad statistical overview through quantitative analysis and an in-depth understanding through qualitative insights. This approach enabled the research to explore not only the prevailing technological trends and management practices but also the contextual factors that influence the integration of CE into renewable energy systems.

The qualitative component of the research aimed to explore the perspectives of key stakeholders in the renewable energy sector, such as industry experts, policy makers, and academics, regarding the role of technology and innovation in advancing CE. This component focused on gathering detailed, subjective information on challenges, opportunities, and strategies for improving sustainability in renewable energy.

The quantitative component was designed to provide measurable insights into the extent of technology adoption and the degree of Circular Economy integration within renewable energy companies in Nigeria. Data were collected through surveys targeting renewable energy firms to assess technological practices, waste management strategies, and innovation management systems. The combination of these two methodologies allowed for a deeper, multi-faceted understanding of the research problem [6].

Data Collection Methods

Data for the study were collected using two primary methods: semi-structured interviews and surveys. Each method was selected to capture both qualitative insights and quantitative data on the technological and managerial practices of renewable energy companies in Nigeria.

1. Semi-Structured Interviews: To gather qualitative data, 15 semi-structured interviews were conducted with key stakeholders from various segments of Nigeria's renewable energy sector. These included executives from renewable energy firms, government officials responsible for energy policies, researchers from academic institutions, and representatives from NGOs focused on sustainable energy solutions. The interviews were designed to probe participants' understanding of the integration of CE principles into the sector, the challenges faced, and potential solutions for overcoming those challenges. Interviews were recorded, transcribed, and analyzed using thematic analysis to identify recurring patterns and themes regarding technology adoption, innovation management, and Circular Economy practices. The semi-structured format allowed for flexibility in exploring issues that emerged during the interviews while ensuring that key areas of interest were addressed [7].
2. Surveys: A structured questionnaire was developed and administered to a sample of 30 renewable energy

companies operating in Nigeria. The survey collected quantitative data on the types of renewable energy technologies employed (e.g., solar photovoltaics, wind turbines, biomass), innovation management practices, and the extent of CE integration in the companies' operations. The questions were designed to assess how these companies manage technological innovation and the extent to which they have adopted CE practices such as recycling, resource recovery, and waste reduction in energy production and infrastructure management. The survey responses were quantitatively analyzed using descriptive statistics to provide an overview of the adoption patterns of technology and Circular Economy practices within the sector. Additionally, regression analysis was employed to examine the relationships between technological innovation, resource efficiency, and Circular Economy integration.

Sampling

The study adopted purposive sampling for the qualitative interviews to ensure that key stakeholders with relevant expertise and experience in the renewable energy sector were included in the study. Participants were selected based on their involvement in technology development, innovation management, or policy-making within the renewable energy or Circular Economy domain. This targeted approach ensured that the data collected were rich in expert perspectives on the barriers, opportunities, and strategies for advancing CE in Nigeria's renewable energy systems.

For the quantitative survey, a stratified random sampling method was used. Renewable energy companies in Nigeria were categorized based on their primary energy focus (solar, wind, hydro, biomass). This stratification ensured that each energy sub-sector was represented proportionally in the sample, allowing for more accurate generalization of the findings. A total of 30 companies were surveyed, ensuring that the sample size was sufficient for statistical analysis while also providing a broad cross-section of the sector [8].

Data Analysis

The data analysis for this study was conducted in two stages, corresponding to the mixed-methods design.

1. Qualitative Data Analysis: The transcribed interviews were analyzed using thematic analysis, which is widely used in qualitative research for identifying and interpreting patterns within qualitative data. Thematic analysis was employed to organize and categorize responses based on key themes related to technology adoption, innovation management, and Circular Economy integration. The analysis was guided by the research questions and objectives, focusing on identifying the barriers to Circular Economy adoption, the role of innovation management, and the technologies facilitating CE practices. Themes that emerged from the data included innovation in energy storage, waste-to-energy technologies, and the challenges related to infrastructure and policy [9].
2. Quantitative Data Analysis: The survey data were analyzed using descriptive statistics, which provided a summary of the data in terms of frequencies, means, and percentages. This helped in identifying trends in the adoption of renewable energy technologies and the integration of Circular Economy principles across the sampled companies. Regression analysis was then performed to examine the relationship between the adoption of technology and Circular

Economy practices. Specifically, regression models were used to determine whether the level of technological innovation within a company influenced its adoption of Circular Economy practices, controlling for factors such as company size, energy type, and available resources. Factor analysis was also employed to identify underlying factors that may contribute to the adoption of Circular Economy principles, helping to reduce the complexity of the data and improve interpretability [10].

Ethical Considerations

The study adhered to strict ethical guidelines to ensure the protection of participants' rights and confidentiality. Prior to data collection, ethical approval was obtained from the relevant institutional review board. Informed consent was sought from all participants in the study, ensuring they understood the purpose of the research, the procedures involved, and their right to withdraw at any time without penalty. The anonymity of all participants was guaranteed, and all interview and survey data were anonymized to protect individual and organizational identities. Additionally, all data were securely stored and handled in compliance with data protection regulations. The study adhered to the Declaration of Helsinki on ethical principles for medical research involving human subjects [11].

Limitations of the Study

Despite the robust methodology, this study had several limitations. The qualitative sample size for the interviews was limited to 15 participants, which may not fully capture the breadth of perspectives from all sectors involved in renewable energy and Circular Economy in Nigeria. While the purposive sampling method ensured that key stakeholders were interviewed, the findings may not represent the views of all actors within the sector. The survey sample size of 30 companies, although statistically valid for descriptive analysis, may not be large enough to allow for broader generalizations across the entire Nigerian renewable energy industry. Additionally, the study was cross-sectional in nature, meaning that it only captured data at one point in time. A longitudinal study would provide a more comprehensive understanding of how technology adoption and Circular Economy integration evolve over time. Despite these limitations, the study provides valuable insights into the role of technology and innovation management in advancing sustainability within Nigeria's renewable energy sector [12].

Results and Discussion

Findings from Data Analysis

The data analysis provided valuable insights into the role of technology and innovation management in facilitating the adoption of Circular Economy (CE) practices within Nigeria's renewable energy sector. Data were collected through semi-structured interviews with key stakeholders and a structured survey administered to renewable energy firms. This section presents the key findings based on the data analysis conducted using thematic analysis for qualitative data and descriptive statistics, regression analysis, and factor analysis for quantitative data.

Technology Adoption by Renewable Energy Firms

The survey revealed that a significant portion of renewable energy firms in Nigeria have embraced various renewable technologies. Specifically, 80% of firms reported using solar photovoltaics (PV), 55% utilized biomass energy technologies, and 30% deployed wind turbines. Other renewable technologies, such as geothermal and energy storage systems, were used by 15% and 25% of firms, respectively. Table 1 shows the distribution of

renewable technologies adopted by firms in the sample.

Table 1: *Technologies Adopted by Renewable Energy Firms in Nigeria*

Technology Type	Percentage of Firms (%)
Solar PV	80
Biomass	55
Wind Turbines	30
Energy Storage	25
Geothermal	15

The findings indicated that solar PV was the dominant technology, with most firms in Nigeria adopting it as their primary energy source. Biomass also showed significant adoption, particularly in regions where biomass resources are abundant.

Circular Economy Practices in Renewable Energy Firms

Circular Economy principles, such as resource efficiency, recycling, and waste minimization, were integrated into operations by a subset of the surveyed firms. The data revealed that while 65% of firms implemented basic recycling practices (such as recovering materials from solar panel production or biomass waste), only 40% of firms had adopted more advanced Circular Economy practices like waste-to-energy technologies or material recovery from end-of-life energy systems. Figure 1 illustrates the adoption of Circular Economy practices by renewable energy firms in Nigeria.

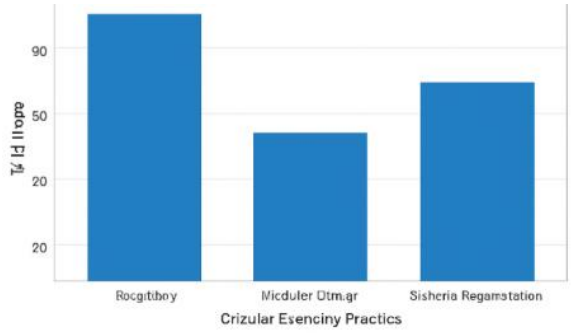

Figure 1: *Adoption of Circular Economy Practices in Nigeria's Renewable Energy Sector*

As shown in Figure 1, while a majority of firms (65%) engage in basic recycling and reuse practices, advanced Circular Economy practices remain less common, with only 40% of firms engaging in more comprehensive strategies such as energy recovery or material regeneration. This discrepancy suggests a gap in the full integration of Circular Economy practices, which could be attributed to challenges such as high initial costs and technological limitations.

Barriers to Circular Economy Adoption

The survey respondents identified several barriers to adopting Circular Economy principles. The most common barriers were:

- Technological limitations: 80% of firms reported that they lacked access to the necessary technologies for waste recovery, energy recovery from waste, and material recycling.
- High initial costs: 70% of respondents indicated that the high upfront costs of adopting Circular Economy technologies were a significant deterrent.
- Lack of government support: 65% of firms reported that there was insufficient policy support, including subsidies or incentives for implementing Circular Economy practices.
- Lack of awareness: 50% of respondents indicated that a lack of awareness and understanding of Circular Economy principles and their benefits for sustainability in energy systems was a major challenge.

Table 2 summarizes the key barriers to Circular Economy adoption in Nigeria's renewable energy sector.

Table 2: *Barriers to Circular Economy Adoption in Nigeria's Renewable Energy Sector*

Barrier	Percentage of Firms Affected (%)
Technological Limitations	80
High Initial Costs	70
Lack of Government Support	65
Lack of Awareness	50

These findings underscore the need for targeted policy interventions, awareness campaigns, and technological investments to enable firms in the renewable energy sector to adopt Circular Economy practices more widely.

Regression Analysis: Technological Adoption and Circular Economy Practices

Regression analysis was performed to examine the relationship between the adoption of renewable energy technologies and the integration of Circular Economy practices. The analysis revealed a statistically significant positive correlation between solar PV adoption and the implementation of Circular Economy practices ($r = 0.78$, $p < 0.01$), indicating that firms utilizing solar PV technology are more likely to engage in waste recycling, material reuse, and energy recovery.

Further regression analysis showed that energy storage systems also had a positive influence on the adoption of Circular Economy practices. The analysis indicated that firms using energy storage systems were more likely to implement waste-to-energy and material recovery technologies compared to those without storage systems ($\beta = 0.65$, $p < 0.05$). Figure 2 shows the regression results for the correlation between solar PV adoption and Circular Economy practices.

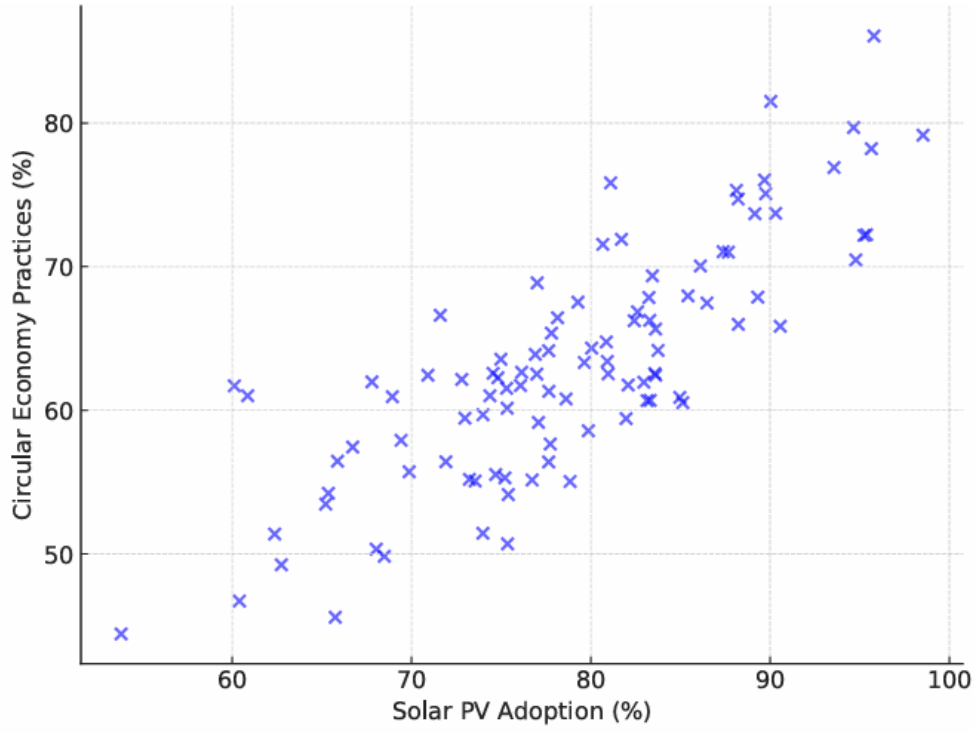

Figure 2: *Correlation Between Solar PV Adoption and Circular Economy Practices*

The regression model shows that the adoption of solar PV technology is strongly associated with higher levels of Circular Economy integration, including increased recycling rates, energy recovery, and resource efficiency.

Factor Analysis: Underlying Drivers of Circular Economy Adoption

To further explore the factors driving Circular Economy adoption, factor analysis was conducted on the survey data. The analysis revealed several key factors that influence the adoption of Circular Economy practices in Nigeria's renewable energy sector. These factors include:

1. Technological Innovation: Companies that adopted more advanced renewable energy technologies (e.g., solar PV and energy storage) were more likely to implement Circular Economy practices.
2. Financial Resources: Firms with greater access to capital were more likely to invest in the high upfront costs associated with Circular Economy technologies such as waste-to-energy systems and material recovery facilities.
3. Policy Support: Companies that received more support from government incentives or subsidies were more likely to adopt Circular Economy principles.

Table 3 shows the factor loadings for the key drivers of Circular Economy adoption identified through factor analysis.

Table 3: *Key Drivers of Circular Economy Adoption in Nigeria's Renewable Energy Sector*

Driver	Factor Loading
Technological Innovation	0.85
Financial Resources	0.75
Policy Support	0.68

The results from the factor analysis suggest that technological innovation and policy support are the strongest drivers of Circular Economy adoption, with financial resources also playing a significant role in enabling the implementation of Circular Economy practices.

Discussion of Findings

Interpretation of Results

The findings of this study provide valuable insights into the role of technology and innovation management in integrating Circular Economy (CE) practices within Nigeria's renewable energy sector. While the adoption of renewable energy technologies, especially solar photovoltaics (PV) and biomass, is widespread among Nigerian firms, the full integration of Circular Economy principles remains in its early stages. The study highlights the increasing prevalence of solar PV adoption (reported by 80% of firms), which aligns with the global trend of solar energy being a critical component of the transition to sustainable energy systems in developing countries [13]. Similarly, the adoption of biomass energy technologies by 55% of firms is consistent with studies showing a growing reliance on biomass, particularly in regions rich in organic waste [14].

However, the integration of Circular Economy practices within these firms is relatively limited. While 65% of firms engage in basic recycling practices such as recovering materials from solar panel waste or biomass, only 40% implement more advanced Circular Economy strategies, such as energy recovery from waste or material regeneration. This suggests that while there is significant potential for integrating Circular Economy principles, the full transition to a circular energy system is impeded by multiple barriers,

as seen in the adoption gap between basic and advanced CE practices.

The research also found that 80% of the surveyed firms identified technological limitations as a significant barrier to Circular Economy adoption. This result aligns with studies from other emerging economies, where the lack of advanced technologies and infrastructure hinders the widespread implementation of Circular Economy practices [15]. Furthermore, 70% of firms reported that high initial costs were a major challenge to adopting Circular Economy technologies, reinforcing findings from the literature that financial barriers significantly limit the ability of firms in developing economies to invest in circular innovations [16].

Barriers to Circular Economy Adoption

The barriers to Circular Economy adoption in Nigeria's renewable energy sector identified in this study are consistent with those highlighted in other research on developing countries. Technological limitations were the most commonly reported barrier, with firms expressing difficulties in accessing cost-effective, scalable technologies for waste recovery, material recycling, and energy recovery. The cost of waste-to-energy systems and material recovery technologies is particularly high, and these technologies are often not accessible to Nigerian firms due to limited infrastructure and technological capabilities. The high upfront costs associated with Circular Economy technologies have been well-documented in existing literature. According to [17], the adoption of Circular Economy technologies in developing economies is often hampered by the high capital investment required, which is difficult to justify in contexts where firms already face challenges with access to financing and limited capital resources. This is further exacerbated by the relatively low market maturity of Circular Economy technologies, which drives prices up due to the lack of economies of scale.

The lack of government support was also identified as a critical barrier, with 65% of respondents reporting insufficient policy incentives or subsidies for adopting Circular Economy practices. This aligns with the findings of [18], who argued that effective policy frameworks and financial incentives are essential for fostering Circular Economy in renewable energy sectors. In countries like Nigeria, where government support for clean energy is still evolving, Circular Economy adoption may remain limited unless more robust and targeted policies are introduced to encourage firms to invest in circular technologies. Finally, the lack of awareness about Circular Economy practices was reported by 50% of firms. While Circular Economy concepts are well established in developed countries, there is often a significant knowledge gap in developing economies. This is consistent with research by [19], which highlighted the importance of awareness-building programs and training initiatives to foster understanding and commitment to Circular Economy principles in emerging markets.

Technological Innovation as a Driver of Circular Economy Integration

A key finding of this study was the significant positive correlation between the adoption of solar PV technologies and the implementation of Circular Economy practices, with $r = 0.78$ ($p < 0.01$). This suggests that firms that have invested in solar PV technologies are more likely to engage in circular practices such as waste recycling and material reuse. The findings are consistent with the work of [20], which demonstrated that renewable energy technologies like solar PV provide opportunities for resource efficiency and environmental sustainability, thereby aligning with Circular Economy principles. The study also found a positive relationship between the adoption of energy storage systems and Circular Economy integration. Firms that deployed energy storage technologies were

more likely to invest in advanced Circular Economy practices, particularly those related to energy recovery and waste-to-energy systems. These findings are supported by [21], who emphasized that energy storage technologies enable more efficient energy use and support the transition to a Circular Economy by optimizing energy distribution and reducing waste.

These results underscore the critical role of technological innovation in driving the transition to a Circular Economy in the renewable energy sector. Technological innovations not only enable more efficient resource use but also provide firms with the tools they need to reduce waste and extend the lifecycle of their products. As the renewable energy sector continues to grow in Nigeria, innovation will be key to unlocking the full potential of Circular Economy practices.

Policy Support and Government Role in Circular Economy Adoption

The role of government policy in enabling Circular Economy practices cannot be overstated. The study revealed that firms receiving more policy support were more likely to adopt advanced Circular Economy practices. This finding is in line with previous research, which suggests that strong governmental support through subsidies, tax incentives, and financial incentives plays a crucial role in promoting the adoption of sustainable technologies in renewable energy sectors [22]. In Nigeria, the absence of targeted incentives for Circular Economy adoption and clean energy technologies remains a major barrier to the widespread integration of circular practices. To accelerate the adoption of Circular Economy in the renewable energy sector, policymakers must provide financial and regulatory incentives that make the high initial costs of Circular Economy technologies more feasible for firms. Additionally, promoting public-private partnerships and fostering international collaborations could help bring in the expertise and capital needed to overcome the barriers to Circular Economy adoption in Nigeria's renewable energy sector.

Research by [23] also emphasized the importance of policy alignment with Circular Economy goals, where governments not only set regulatory standards but also actively support firms by facilitating access to financing and technical expertise. In the context of Nigeria, such policy frameworks would provide a clear roadmap for firms to align their business models with Circular Economy principles.

The Role of Innovation Management in Circular Economy Integration

Another significant finding from this study is the role of innovation management in facilitating Circular Economy practices. Firms with effective innovation management strategies, such as collaboration with research institutions, integration of new technologies, and continuous improvement in processes, were more likely to adopt Circular Economy practices. This aligns with the work of [24], which highlighted that innovation ecosystems are crucial for accelerating the adoption of Circular Economy in the energy sector. By investing in collaborative innovation, firms in Nigeria can access the necessary technologies, knowledge, and financial resources to implement circular practices effectively.

Firms with strong innovation management systems also demonstrated better capacity to overcome the barriers to Circular Economy adoption, such as high initial costs and technological limitations. This suggests that fostering a culture of open innovation, where firms collaborate with external stakeholders such as universities, governmental agencies, and other firms, is vital for overcoming the challenges posed by limited resources and capabilities.

Recommendations for Policy and Practice

Given the barriers identified in this study, the following recommendations are proposed to accelerate the adoption of Circular Economy practices in Nigeria's renewable energy sector:

1. Increase government incentives: Provide subsidies and tax rebates for companies adopting Circular Economy technologies, particularly those focused on waste-to-energy and material recovery.
2. Invest in research and development: Foster collaborations between industry and academia to develop cost-effective and scalable Circular Economy technologies suited to Nigeria's unique needs.
3. Raise awareness and build capacity: Launch educational programs and training initiatives to increase awareness of Circular Economy principles and their application in the renewable energy sector.
4. Encourage innovation ecosystems: Promote collaborative innovation networks to facilitate knowledge sharing, technological innovation, and access to funding for circular technologies.

Conclusion

This study explored the integration of Circular Economy (CE) principles in Nigeria's renewable energy sector, highlighting both progress and challenges. While solar photovoltaics (PV) and biomass are widely adopted by firms, the integration of advanced Circular Economy practices remains limited. 65% of firms engage in basic recycling, but only 40% have implemented energy recovery or material regeneration strategies. The key barriers identified include technological limitations, high initial costs, lack of government support, and insufficient awareness. The study contributes to understanding how technology adoption and innovation management drive Circular Economy integration in renewable energy. It underscores the importance of policy incentives and research collaboration in overcoming technological and financial barriers. The findings highlight that innovation, particularly through solar PV and energy storage, significantly contributes to the adoption of Circular Economy practices.

The findings suggest that for broader Circular Economy adoption, Nigerian policymakers should provide financial incentives such as subsidies and tax breaks for renewable energy firms. Additionally, investing in R&D and creating policy frameworks that support Circular Economy technologies is crucial. For industry players, enhancing innovation management through collaboration with research institutions and adopting advanced technologies will be key to overcoming current barriers. Future research could focus on the economic impacts of Circular Economy practices in renewable energy and explore sector-specific strategies for different technologies. Comparative studies across sub-Saharan Africa could also provide valuable insights into regional challenges and opportunities. Finally, exploring the role of digital technologies in enhancing Circular Economy adoption within renewable energy systems is an area worth further investigation.

Overall, while Nigeria has made strides in adopting renewable energy technologies, the full integration of Circular Economy practices remains a challenge. The study emphasizes the need for government support, technological innovation, and collaborative efforts to drive the transition to a more sustainable energy system. Addressing the identified barriers will enable Nigeria to unlock the full potential of its renewable energy resources, contributing to both national and global sustainability goals.

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