The Role of Digital Applications in Transforming Recycling Industry in Egypt: A Case Study of Retreading Tires at Bridgestone

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ABSTRACT

This study explores the transformative role of digital applications in Egypt's recycling industry, specifically focusing on Bridgestone's tire retreading process. It examines how digital tools can enhance recycling efficiency, increase public participation, and create economic opportunities while addressing challenges such as infrastructure limitations and lack of awareness. Bridgestone's tire retreading process demonstrates how digital applications can reduce costs, extend tire lifespan, and promote sustainability. The study highlights the importance of targeted public awareness efforts, infrastructure investments, and regulatory incentives in maximizing the benefits of digital technology in Egypt's recycling sector.

1. Introduction

Tire waste represents a significant environmental and public health challenge worldwide. Over 1.5 billion end-of-life tires (ELTs) are thrown each year, with just a small fraction recycled or repurposed [1]. Traditional disposal practices, such as landfilling and open burning, contribute to environmental degradation by releasing hazardous compounds into the air, soil, and water. Tire fires, for example, can burn for months, producing dangerous fumes, whilst discarded tires in landfills leach harmful compounds that contaminate ecosystems [2]. These behaviors not only harm the environment but also offer major health hazards, such as respiratory disorders and the development of vector-borne illnesses like malaria and dengue fever [3].

In Egypt, the problem of tire waste is particularly acute due to rapid urbanization, industrialization, and population growth. The country's tire manufacturing business uses around 65% of the world's natural and synthetic rubber, resulting in high production costs and resource scarcity [4]. The development of automobiles and industrial activity has resulted in an increase of end-of-life tires, adding to the strain on waste disposal systems. Despite the environmental and economic benefits of recycling, Egypt's recycling rates remain low, due to antiquated infrastructure and low public awareness [5]. This emphasizes the critical need for novel approaches to manage the growing tire waste crisis and promote sustainable development. Digital applications have developed as a transformative waste management tool, with the ability to increase recycling

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efficiency, reduce environmental impact, and involve the public in sustainable habits. Mobile apps, IoT sensors, and AI-powered analytics are transforming waste collection, processing, and recycling systems worldwide [6]. Bridgestone's tire retreading process, for example, highlights how digital technologies may improve recycling processes, save costs, and increase tire lifespan [7]. In Egypt, initiatives like as Bekia and E-Tadweer have showed promise in terms of public participation and operational effectiveness in recycling [8,9]. However, the use of advanced digital tools in Egypt's recycling business is still underexplored, indicating a crucial research gap.

This study looks at the importance of digital technologies in upgrading Egypt's tire recycling business, specifically Bridgestone's retreading process. The study addresses major issues such as infrastructure constraints, a lack of awareness, and high manufacturing costs, while also investigating how digital tools might improve recycling efficiency and public participation. This project intends to provide practical insights for policymakers, industry stakeholders, and researchers by exploring the potential of digital technology to improve waste management practices, ultimately contributing to Egypt's transition to a more sustainable and circular economy.

2. Literature Review

The growing global concern about tire trash has prompted substantial study into environmentally friendly disposal and recycling technologies. Studies have shown that incorrect tire disposal poses environmental and public health problems, such as soil contamination, air pollution from tire fires, and the spread of vector-borne diseases [1,3]. Traditional approaches like landfilling and incineration have proven ineffective, frequently aggravating environmental degradation [2]. In response, academics have investigated alternate options, such as tire retreading, pyrolysis, and material recovery, to reduce the environmental impact of end-of-life tires (ELTs) [10].

Tire management and disposal have become a major environmental issue worldwide, with more than 1.5 billion end-of-life tires (ELTs) destroyed each year [1]. Rapid urbanization and industry in Egypt have worsened the problem, making tire recycling an urgent priority for long-term growth. Recycling, defined as the act of recovering materials from waste and changing them into new goods, is critical in addressing these difficulties. However, tire recycling has particular challenges due to their complex chemical and mechanical structure, which is optimized for durability and abrasion resistance [2]. Traditional approaches, like as landfilling and incineration, have proven ineffective, often accelerating environmental degradation. For example, tire fires can last for months, releasing toxic fumes, while discarded tires in landfills leach harmful chemicals into the soil and water [5].

Retreading, which involves reusing the structural components of an old tire by putting a new tread, has emerged as a cost-effective and environmentally friendly alternative. This method includes removing the worn tread, examining the tire for deterioration, and applying a fresh layer of rubber to the casing [11]. Despite its benefits, only around 30 million of the 280 million tires thrown each year in the United States are retreaded or reused, leaving the bulk to be managed in less sustainable ways [5]. This emphasizes the critical need for novel ideas to improve tire recycling efficiency while minimizing environmental effect.

Mechanical recycling, chemical recycling, and biological recycling are examples of recycling technologies that have been created to handle the various waste management concerns. Mechanical recycling is the physical transformation of waste materials into new products using methods such as shredding and melting, which is commonly utilized for plastics and metals [12]. Chemical recycling, on the other hand, uses chemical methods to break down polymers into monomers, allowing the production of new high-quality materials from recycled plastics [13]. Biological recycling breaks down organic waste materials through enzymatic or microbial degradation to produce valuable products such as compost [14]. These technologies present intriguing options for tire recycling, but their application necessitates substantial expenditure and infrastructure.

Digital applications are transforming trash management by increasing efficiency, lowering costs, and involving the general public. These software applications, which are intended to run on digital devices and platforms, include features ranging from communication to complex data processing [6]. User interfaces (UI) allow users to engage with the application, while backend infrastructure handles data processing and storage [15,14]. Tools like integrated development environments (IDEs) and cloud computing platforms have made it easier to design and implement digital solutions, allowing for real-time data tracking and recycling operations optimization [16,17].

Digital tools have been found to increase recycling efficiency and public engagement. For example, in Egypt, smartphone apps like as Bekia and E-Tadweer provide users with recycling schedules, drop-off sites, and participation incentives [8,9]. These applications not only improve operational efficiency, but they also increase public awareness and involvement, both of which are crucial to the success of recycling projects. Globally, programs such as D-Waste Atlas and EPA iWARM have proved the power of digital platforms in benchmarking waste management data and calculating energy savings from recycling. Furthermore, scrap metal recyclers can use applications like iScrap to find recycling sites and submit images of objects for review, expediting the recycling process [18].

The incorporation of digital tools into tire recycling represents a possible solution to Egypt's challenges of inefficiency, poor public participation, and outmoded methods. Machine learning (ML) and deep learning technologies were used to forecast tire casing life and identify reusable tires by image recognition, with a 99.78% accuracy [19,20]. These improvements not only improve resource efficiency but also minimize trash, resulting in a more sustainable recycling ecosystem. For example, ML models use historical data, telematics, and finite element modeling to estimate tire casing life, allowing fleet managers to make more informed decisions about tire retreading [19]. Similarly, deep learning algorithms utilize image recognition to recognize reusable truck tires.

Despite the potential of digital technologies, their use in tire recycling, particularly in underdeveloped countries such as Egypt, is underexplored. Existing research has mostly focused on technological breakthroughs in waste management in rich countries, creating a void in understanding how these tools might be applied to locations with limited infrastructure and resources. For example, Egypt's recycling business has obstacles such as high manufacturing costs, shortage of resources, and little public engagement. However, digital applications such as Bekia and E-Tadweer have showed potential in overcoming these hurdles by enhancing waste collection, giving recycling information, and encouraging public participation [8,9].

Recent advances in tire life evaluation have shown that there is a huge opportunity to increase commercial vehicle tire remanufacturing. [21] present an approach that uses machine learning and data science methodologies to assess the remaining casing health of tires, allowing for more accurate retread ability judgments. Their approach separates tire performance across running situations by assessing utilization characteristics such as fleet behavior and wheel position. This methodology tackles the conservatism inherent in present procedures, in which tires are frequently retired prematurely due to a lack of accurate knowledge about their remaining service life. The authors estimate that deploying such strategies throughout the United States.

The commercial vehicle tire industry may reduce main feedstock use by 580 metric kilotons per year, save 37.1 petajoules of energy, and decrease CO_2 emissions by 1476 metric kilotons. These findings show the transformative potential of data-driven approaches to increasing tire life, decreasing waste, and promoting sustainable behaviors in the freight industry [21].

Also, recent advances in car tire technologies, such as the creation of "smart tires" with integrated sensors, have dramatically improved safety, fuel efficiency, and performance by allowing for real-time monitoring of pressure, temperature, and tread depth. The use of Nano generators and retreading procedures emphasizes the industry's transition to sustainability and energy independence. As driverless vehicles become more common, the collaboration of intelligent tires and autonomous driving algorithms is expected to set new standards for safety and efficiency. However, there are still hurdles in commercializing energy harvesters for tire pressure monitoring systems (TPMS) and creating sophisticated tire wear monitoring technologies. These advancements establish intelligent tires as essential components of safer and more sustainable transportation networks [22].

The environmental impact of waste materials has received substantial attention in recent years, with waste rubber emerging as a major concern. Waste rubber, sometimes known as "black pollution," offers significant ecological problems due to its rising quantity and toxicants released into the environment. [23] provide a thorough analysis of waste rubber research, emphasizing the difficulties connected with its disposal, management, and recycling. By reviewing 192 papers, the authors highlight the critical need for long-term, large-scale trials as well as the development of efficient recycling systems to reduce environmental concerns. Their research emphasizes the necessity of understanding toxicant behavior and undertaking full ecological risk assessments, while also offering sustainability strategies to combat waste rubber contamination. This work reframes waste rubber as a worldwide environmental issue and advocates for additional research to attain ecosystem sustainability [23].

In conclusion, the literature emphasizes the environmental and economic issues caused by tire waste, the ability of digital technologies to revolutionize recycling processes, and the need for innovative solutions in Egypt's tire recycling business. This project intends to help Egypt establish a sustainable and efficient recycling ecosystem by incorporating digital tools and encouraging public participation. The utilization of technology such as machine learning, deep learning, and mobile applications provides a road to increasing recycling efficiency, reducing waste, and creating economic opportunities, paving the way for a greener future.

3. Material and Methods

3.1. Case Study: Retreading Tires at Bridgestone

Bridgestone Corporation, a Japanese multinational firm, is one of the world's major tire and rubber manufacturers. Bridgestone was founded in 1931 by Shojiro Ishibashi in Kurume, Japan, and has since developed into a global leader with operations in over 150 countries. The company's retreading process is a major subject of this research since it demonstrates how digital tools may improve recycling efficiency and sustainability.

3.2. Challenges in Retreading

Bridgestone faced several challenges when implementing tire retreading, which slowed its adoption as a viable alternative. One of the main challenges was inconsistency in quality control, which raised worries about the safety and reliability of retreaded tires. Early retreading processes sometimes resulted in uneven tread application, which raised the risk of tire failure. Furthermore, a lack of contemporary technology made it difficult to adequately test tire casings, resulting in the retreading of unsuitable tires. These difficulties contributed to negative consumer views, with many seeing retreaded tires as inferior to new ones.

Another significant challenge was a lack of infrastructure for collecting and processing worn tires. Bridgestone needed to create a system to ensure that worn tires were thoroughly inspected, classified, and made available for retreading. This necessitated major investment in logistics and supply chain management. Furthermore, the corporation had to handle environmental issues associated with the retreading process, such as energy usage and carbon emissions. Bridgestone sought to ensure that retreading was both cost-effective and environmentally friendly.

3.3. Technological Innovations

To address these difficulties, Bridgestone made significant investments in new technologies such as machine learning (ML), the Internet of Things (IoT), and automated inspection systems. These advances improved the retreading process, making it more efficient, dependable, and sustainable.

- **Machine Learning (ML):** Bridgestone used machine learning (ML) methods to forecast tire casing life and retreadability. These algorithms assist fleet operators in making intelligent tire retread decisions by using historical data, telematics, and finite element modeling. For example, ML models can determine which tires are appropriate for retreading and predict how many retreading cycles a tire may withstand before needing to be replaced.
- **Internet of Things (IoT):** sensors integrated in tires track performance in real time, providing useful information on tire wear, pressure, and temperature. This data is sent to fleet management systems, allowing operators to optimize tire consumption and minimize downtime. IoT-enabled tires also allow for predictive maintenance, which ensures that tires are retreaded or replaced before they fail.
- **Automated Inspection Systems:** Bridgestone's Bandag retreading process employs automated inspection devices to check tire casings for damage and wear. These systems use digital scanning and imaging technology to detect even slight flaws, guaranteeing that only high-quality casings are reused. This level of precision was not attainable using manual examination methods.

3.4. Digital Tools in Retreading

Bridgestone's retreading process is primarily reliant on digital tools to increase efficiency and quality. One of the most notable developments is the Bandag Retread System, which incorporates digital technologies into every stage of the retreading process as following:

- **Tread Design Software:** Bridgestone uses complex technologies to create individual tread patterns for certain driving situations. This ensures that retreaded tires work just as effectively as fresh tires, even in harsh settings.
- **Real-Time Monitoring:** IoT sensors incorporated in retreaded tires give real-time performance data, allowing fleet operators to track tire health and optimize utilization. This lowers the danger of tire failure and increases the life of retreaded tires.
- **Fleet Management Apps:** Bridgestone provides mobile apps like FleetPulse that enable fleet operators to track tire performance, plan maintenance, and receive notifications about potential issues. These apps also offer insights into fuel economy and cost savings, allowing operators to optimize the value of retreaded tires.

3.5. Economic and Environmental Benefits

Bridgestone's retreading method provides considerable economic and environmental benefits. Reusing tire casings saves the corporation 50% on raw materials like rubber and steel. This not only decreases production costs, but also reduces the environmental impact of tire manufacture. Furthermore, retreading cuts CO_2 emissions by half when compared to new tire production, which helps Bridgestone meet its environmental goals.

The economic benefits extend to fleet operators, who can save 30-40% on tire replacement expenses by employing retread tires. For example, a single retread tire is substantially less expensive than a new tire while providing comparable performance and durability. Bridgestone's digital tools, such as predictive maintenance and real-time monitoring, add to these savings by lowering downtime and optimizing tire consumption.

3.6. Global Impact and Future Directions

Bridgestone's retreading process has a global reach, with operations in North America, Europe, and Australia. The company's Bandag retreading process is well-known for its quality and dependability, making it a top choice for fleet operators worldwide. Bridgestone continues to develop in the tire retreading industry, with an emphasis on incorporating digital technologies and encouraging sustainability.

Looking ahead, Bridgestone intends to increase its retreading services while also reducing the environmental impact of tire manufacture. To develop more sustainable tires, the company is looking at new technologies such as recycled carbon black (rCB) and bio-based materials. Bridgestone is pioneering a better future in the tire industry by combining digital innovation and a commitment to sustainability.

3.7. Bridgestone before and after retreading tires

Before implementing improved retreading technology, Bridgestone suffered with variable quality control, as early retreading procedures sometimes resulted in uneven tread application and safety concerns. The lack of digital instruments made it difficult to fully inspect tire casings, necessitating the retreading of inappropriate tires. Furthermore, the disposal of worn-out tires led to environmental contamination, since many tires ended up in landfills or were burned, emitting harmful fumes. The development of new tires necessitated the use of considerable raw materials such as rubber and steel, as well as a large quantity of energy, which exacerbated the environmental impact. Bridgestone improved their retreading process by incorporating digital tools such as machine learning (ML) and the Internet of Things (IoT). ML algorithms can now forecast tire casing life and retreadability, and IoT sensors monitor tire performance in real time, lowering the chance of failure. Automated inspection methods provide exact tread application and thorough casing inspections, hence increasing the quality and durability of retreaded tires. These improvements have decreased fleet operators' expenditures by 30-40% while minimizing environmental effect by reusing tire casings and lowering CO_2 emissions in half. As a result, retreaded tires are increasingly regarded as a safe, affordable, and environmentally friendly alternative to new tires. This section is formulated as follows.

Table 1: *The comparison between before and after retreading tires at Bridgestone.*

Aspect	Before Retreading	After Retreading
Tire Performance	Worn, reduced grip, lower traction	Restored grip, traction, and safety
Cost to Fleet Owners	High replacement costs	Significant savings (up to 30-40%)
Environmental Impact	High environmental impact (waste, resource use)	Lower environmental impact (less waste, resource conservation)
Tire Lifespan	Shorter lifespan, frequent replacements	Extended lifespan with multiple retreading cycles
Disposal and Waste	Tires often end up in landfills	Reduced waste, more efficient recycling
Technology Utilization	Basic tire monitoring and manual inspection	Advanced digital monitoring, AI, IoT, automated processes
Fleet Management	Basic manual tracking of tire conditions	Real-time tracking and data-driven maintenance with fleet management apps

This study sought to investigate the role of digital apps in reforming Egypt's recycling business, with an emphasis on improving recycling practices, conserving the environment, and assisting users in identifying recyclable products. To do this, a qualitative study technique was used to assess both conventional and modern recycling systems. The purpose was to look into how digital tools may save time, enhance environmental outcomes, and add value to Egypt's economy by encouraging more effective recycling methods.

A mixed-methods approach was used to collect both quantitative and qualitative data, resulting in a complete understanding of digital technologies' impact on the recycling business. A survey was used to collect quantitative data on the use and effectiveness of digital apps, while semi-structured interviews with key stakeholders in the recycling and tire retreading industries provided qualitative data. This mix of methodologies enabled the researchers to investigate not just the numerical efficacy of digital tools, but also the perspectives, difficulties, and possibilities perceived by industry leaders.

Data was collected from both primary and secondary sources. Semi-structured interviews were used to collect primary data from executives in the private sector, particularly in the tire manufacturing industry. These interviews provided insights into how digital tools were employed in the recycling process, as well as identifying important issues and potential in the sector. Secondary data were gathered from a variety of trustworthy and public sources to provide more context and a more complete understanding of the impact of digital technology in the recycling business.

The study examined the following hypotheses: H1: Increased integration of digital applications will enhance recycling efficiency, resulting in less pollution, better resource conservation, and a smaller environmental imprint. H2: Increased public awareness efforts will teach the public about recycling and digital alternatives, resulting in higher participation rates. H3: Increased integration of digital applications will have a favorable economic impact, including job creation, revenue production, and new economic opportunities in the recycling business. H4: Increased public awareness campaigns will boost recycling efficiency by teaching people about the recycling business and digital solutions.

The survey involved 55 respondents from various sectors of the recycling industry, including waste management companies, and individuals engaged in the tire retreading sector. The survey consisted of several sections aimed at capturing a range of data: demographic information, challenges facing the recycling industry, awareness of digital tools, the impact of digital applications on recycling efficiency, and the role of digital tools in encouraging public participation in recycling efforts. This combination of different types of questions allowed for a nuanced understanding of the stakeholders' views on digital applications in recycling.

The survey results confirmed these ideas, with 36.36% of respondents evaluating digital tools as "Effective" in enhancing recycling efficiency, 60% identifying job creation as a key economic gain, and 70% considering public awareness campaigns "Very Important" for encouraging the use of digital tools in recycling.

3.8. Demographic Information of Respondents

Table 2: *Demographic Breakdown*

Age Range	Frequency	Percentage (%)
25-34	20	36.36%
35-44	18	32.73%
45+	17	30.91%

Table 3: *Educational Level*

Education Level	Frequency	Percentage (%)
High Education	25	45.45%
Master's Degree	15	27.27%
PhD	10	18.18%
Other	5	9.09%

3.9. Challenges Facing the Recycling Industry in Egypt

Respondents identified several challenges faced by the recycling industry in Egypt. The biggest challenge reported is Poor infrastructure (55%), followed by Lack of awareness (50%) and High costs of recycling technologies (45%).

The Figure below would show the frequency of responses for each challenge, with Poor infrastructure being the most commonly selected challenge at 55%.

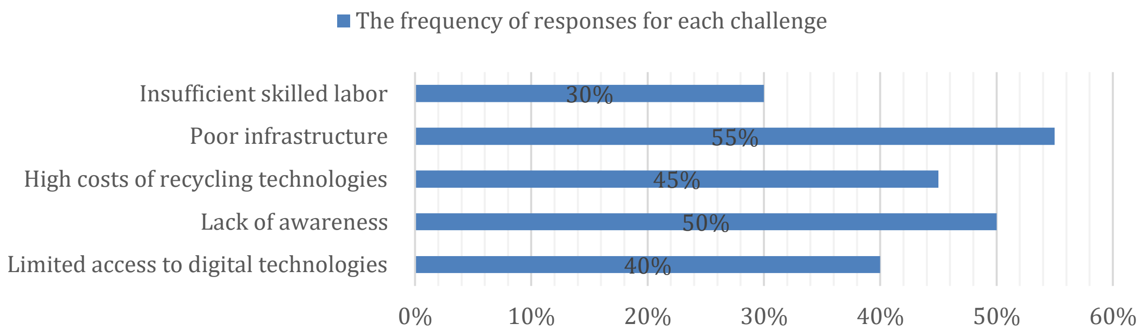

Figure 1. Challenges in the Recycling Industry in Egypt

To provide further insight, the mode (most frequently chosen challenge) is Poor infrastructure (55%). we could also compute average percentage of responses across the challenges, which would give us an overall picture of how respondents view the industry's struggles

$$\text{Average} = \frac{40\%+50\%+45\%+55\%+30\%}{5} = 44\% \quad (1)$$

So, on average, the challenges are perceived at 44% across all respondents.

3.10. Awareness of Digital Tools in the Egyptian Recycling Industry

Participants were asked if they were aware of digital tools used in the recycling business. The findings revealed variable levels of awareness among different digital technologies. Waste tracking and management software was the most known tool, with 50% of respondents (28 individuals) familiar with it. 40% (22 respondents) were aware of mobile apps used to schedule waste pickup, while 25% (14 respondents) were aware of IoT sensors used to monitor waste levels. Finally, 10% (6 respondents) said they were familiar with the use of artificial intelligence to sort things. Figure 2 showing the percentage of respondents aware of each digital tool, with waste tracking software being the most recognized at 50%.

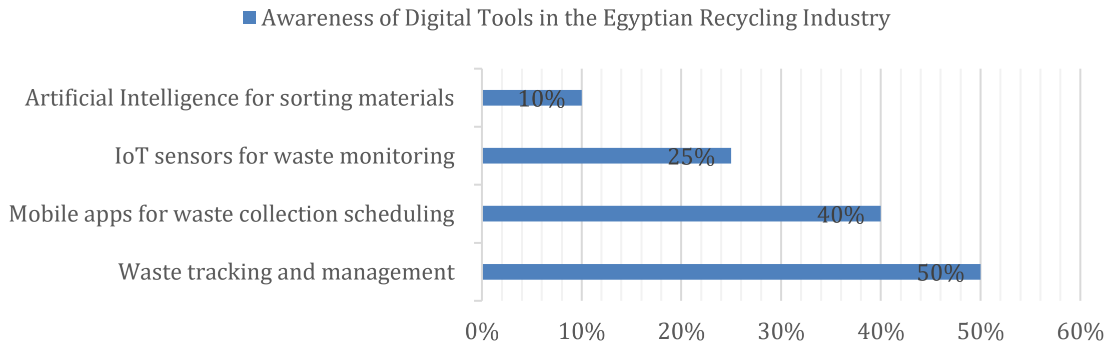

Figure 2. Awareness of Digital Tools in the Egyptian Recycling Industry

The most recognized digital tool is Waste tracking software at 50%. If we wanted to calculate the mean percentage of awareness across these tools:

$$\text{Average Awareness} = \frac{50\%+40\%+25\%+10\%}{4} = 31.25\% \quad (2)$$

So, on average, respondents are aware of 31.25% of the digital tools presented.

3.11. Impact of Digital Tools on Recycling Efficiency

On a scale from 1-5, participants were asked to rate the impact of digital tools on improving recycling efficiency in Egypt. The distribution of responses was as follows.

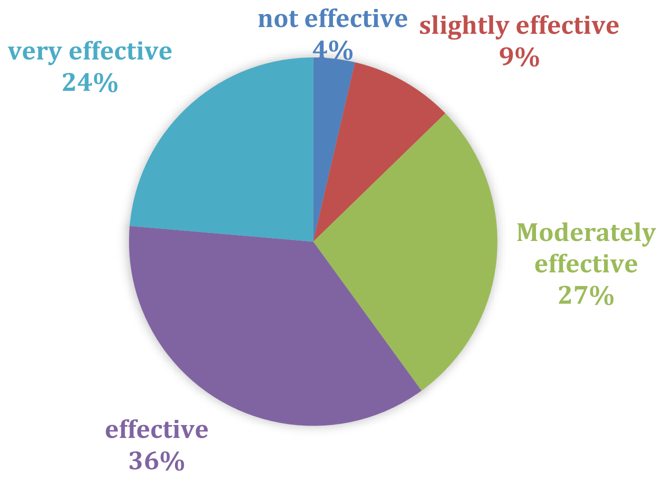

Figure 3. Impact of Digital Tools on Recycling Efficiency

To get a better understanding of how the participants feel about the effectiveness of digital tools, we can calculate the weighted average score. We assign each response a value (1 for "Not effective," 2 for "Slightly effective," etc.) and calculate the average as following:

$$\text{Weighted Average} = \frac{(2\times 1)+(5\times 2)+(15\times 3)+(20\times 4)+(13\times 5)}{2+5+15+20+13}$$

$$= \frac{2+10+45+80+65}{55} = \frac{202}{55} \approx 3.67 \quad (3)$$

This gives us an average rating of 3.67, which is between "Moderately effective" and "Effective." This indicates that the participants generally view digital tools as having a positive impact on recycling efficiency.

3.12. Role of Digital Applications in Encouraging Recycling Participation

Respondents were asked how they think digital applications could help increase public participation in recycling efforts. This section was formulated as follows.

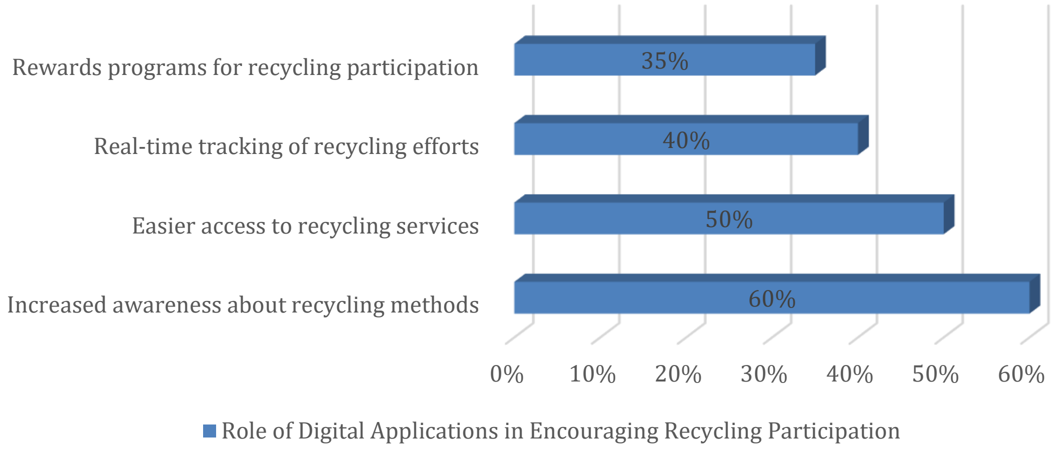

Figure 4. Role of Digital Applications in Encouraging Recycling Participation

The most frequent response is increased awareness (60%).

$$Average = \frac{60\%+50\%+40\%+35\%}{4} = 46.25\% \tag{4}$$

3.13. Perceived Impact of Digital Applications on Economic Opportunities

Participants were asked about the impact of digital applications on economic opportunities within the recycling industry. The most frequently mentioned impacts were:

- Increased job creation – 60% (33 respondents)
- Revenue generation through digital platforms – 45% (25 respondents)
- Increased efficiency leading to cost savings – 50% (27 respondents)
- Expansion of the recycling market – 40% (22 respondents)

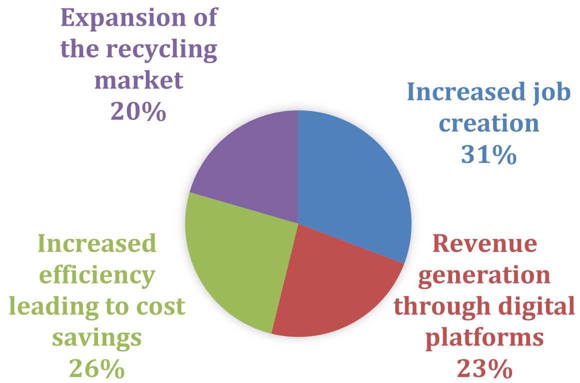

Figure 5. Economic Opportunities in the Recycling Industry

The most frequent response is Increased job creation (60% of respondents). This shows a high perceived value of digital tools in fostering employment within the recycling industry. The least frequent response is Expansion of the recycling market (40%), but it still indicates a significant perception of the potential for growth. Mean percentage of respondents perceiving positive economic impacts:

$$\text{Average} = \frac{60\%+45\%+50\%+40\%}{4} = 48.75\% \tag{5}$$

So, on average, 48.75% of respondents believe that digital applications in the recycling industry will have a positive economic impact. The majority of participants (60%) consider job creation the most important economic impact. On average, respondents think digital applications can positively influence economic opportunities in the recycling industry, with 48.75% of responses indicating a strong belief in these benefits.

3.14. Public Awareness Campaigns and Digital Tools

When questioned about the importance of public awareness campaigns in encouraging people to use digital tools for recycling, the responses were as follows:

- Very Important – 70% (38 respondents)
- Important – 20% (11 respondents)
- Unimportant – 10% (6 respondents)

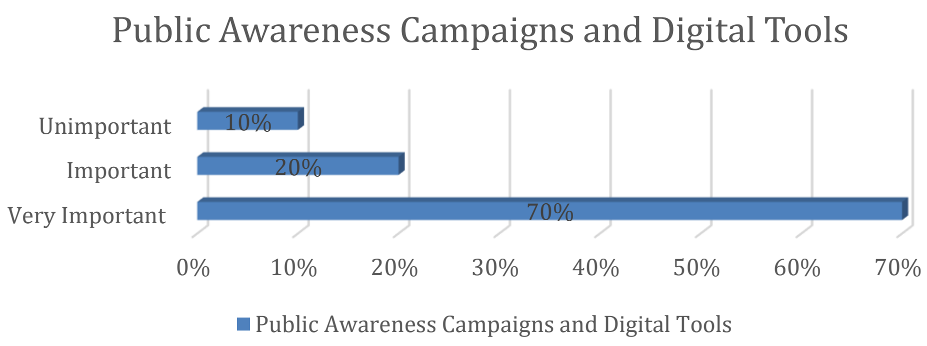

Figure 6. Importance of Public Awareness Campaigns

Figure 6 showing the importance of awareness campaigns, with the majority (70%) considering it "Very Important".
The majority of respondents (70%) consider public awareness campaigns to be Very Important in encouraging the use of digital tools for recycling. This highlights a strong belief in the need for awareness-raising efforts to drive the adoption of digital solutions.
Only 10% of respondents felt that public awareness campaigns were Unimportant, suggesting minimal resistance or indifference toward such campaigns.
Mean percentage of respondents perceiving the importance of public awareness:

$$\text{Average} = \frac{70\%+20\%+10\%}{3} = 33.33\% \quad (6)$$

Since the response categories are very important, important, and unimportant, calculating the average percentage is a bit tricky, but we can infer that 33.33% of respondents consider the campaigns as moderately or less impactful, while the remaining 66.67% view them as crucial.

Public awareness campaigns are considered "Very Important" by 70% of respondents. This strong sentiment indicates a consensus on the necessity of promoting awareness to encourage the adoption of digital tools in recycling.

4. Findings

The findings indicate that digital tools are seen as highly helpful in enhancing recycling efficiency and encouraging public participation. According to the survey results, cost reductions, increased awareness, and digital performance monitoring tools are significant factors in persuading fleet operators to use retread tires. Concerning the issues in the recycling industry, data from 55 respondents suggested that a lack of awareness and poor infrastructure are important barriers in Egypt's recycling sector. This highlights the need for improved recycling education and significant infrastructure investment. These findings are consistent with existing literature, which highlights the importance of public awareness and infrastructure in increasing recycling rates. The survey results showed many obstacles for Egypt's recycling business. Figure 7 depicts the most major difficulties as poor infrastructure (55%), followed by a lack of awareness (50%). These findings underscore the importance of targeted infrastructure expenditures as well as public awareness initiatives to increase recycling efficiency and participation.

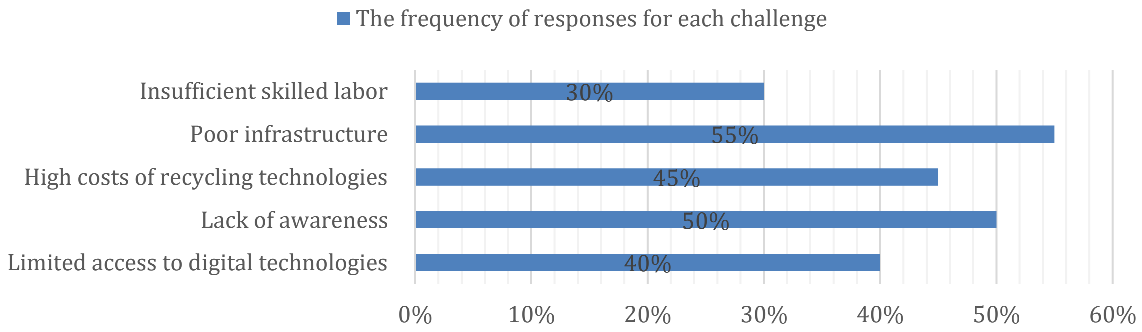

Figure 7. Challenges in the Recycling Industry in Egypt

The majority of respondents felt that digital tools, such as waste tracking software and mobile apps, have the potential to dramatically enhance recycling in Egypt. Forty percent evaluated their impact as "significant," while fifty percent said these methods may increase public participation in recycling. Furthermore, when discussing retreaded tires, respondents cited cost savings and enhanced tire performance monitoring as significant reasons for fleet operators to use retreaded tires. Digital tools, particularly tire monitoring systems, were viewed as critical for increasing productivity and lowering costs, hence encouraging sustainable practices in the industry.

5. Conclusion

This study examined the role of digital applications in modernizing Egypt's recycling industry, namely Bridgestone's tire retreading process. The study found that digital solutions like garbage tracking software and IoT sensors considerably boost recycling efficiency and public participation. Bridgestone's retreading process exemplifies how digital technologies may cut costs, increase tire life, and promote sustainability. However, barriers such as insufficient infrastructure and low awareness prevent widespread implementation. The findings of this study address the transformative potential of digital applications in the recycling industry, providing useful insights for stakeholders looking to promote sustainability and innovation. With the appropriate combination of education, infrastructure, and governmental backing, digital tools can help modernize Egypt's recycling industry, paving the way for a greener, more sustainable future. The hypotheses were successfully tested, revealing that digital tools may improve recycling efficiency, create economic opportunities, and increase public participation. However, additional efforts are required to solve infrastructure and awareness limitations in order to fully reap the benefits of digital technology in the recycling industry.

To fully realize the promise of digital tools, Egypt requires a comprehensive strategy that combines infrastructural expenditures, educational initiatives, and public awareness campaigns. Targeting younger, more educated people who are more likely to accept these technologies may hasten their incorporation. Additionally, enabling policies, such as economic incentives and investment in technology infrastructure, are required for widespread adoption.

Overall, with the appropriate combination of education, infrastructural upgrades, and government assistance, digital tools have the potential to revolutionize Egypt's recycling business, promoting environmental protection, economic development, and a more sustainable future.

To ensure that the conclusions of this study are applied practically, concrete implementation procedures must be outlined. These initiatives are intended to solve issues highlighted in Egypt's recycling business, such as poor infrastructure, low public awareness, and restricted adoption of digital solutions. This section provides a roadmap for stakeholders to turn recommendations into real achievements that promote sustainability, economic growth, and environmental preservation as the following:

1. Infrastructure Development: Invest in modern recycling facilities with IoT sensors and AI-powered sorting systems.
2. Public Awareness Campaigns through social media, mobile apps, and community workshops.
3. Regulatory Incentives: Introduce tax breaks for businesses that use digital tools.
4. Collaboration with Industry: Encourage relationships between recycling companies and technology companies.
5. Research and Development: Support long-term, large-scale trials to investigate ecological implications.

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