



REVIEW ARTICLE

An overview of wastepaper and carton recycling in Oman

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Abstract

This paper provides an in-depth analysis of wastepaper and carton recycling in Oman, emphasizing key statistics, challenges, and the regulatory framework shaping the sector. Oman produces approximately 2.4 million tons of municipal solid waste (MSW) annually, with wastepaper and carton comprising 25% (around 600,000 tons). Although the current recycling rate for these materials is only 12%, opportunities for improvement exist through advancements in infrastructure, technology, and public engagement. The be'ah and private sector stakeholders play a central role in recycling initiatives. The National Strategy for Integrated Waste Management (NSIWM) aims to achieve an ambitious 80% recycling rate by 2030, driven by policies like Extended Producer Responsibility (EPR) and public awareness efforts. The paper highlights recycling's environmental and economic benefits, including reduced landfill use and job creation. It identifies key challenges, such as low public awareness and insufficient infrastructure, and offers actionable recommendations, including enhanced public education, technological investment, and strengthened regulatory enforcement.

Keywords: Waste management, Wastepaper recycling, Sustainability, Economic diversification, Recycling initiatives.

Introduction

Oman faces significant challenges in managing its waste effectively due to rapid urbanization, economic growth, and an increasing population. Recycling wastepaper and cartons helps reduce the burden on landfills, safeguards natural resources, saves energy, and mitigates greenhouse-gas emissions, making it an essential component of sustainable development (Kaza *et al.*, 2018; Okedu *et al.*, 2022; Umar, 2022).

Oman's recycling rate for paper and carton is 12%, lower than the global average of 19% (UNEP, 2020). This low rate

necessitates improved infrastructure, public awareness, and effective waste management policies. The Sultanate of Oman is working to improve waste management practices and increase recycling rates through entities like the Oman Environmental Services Holding Company (be'ah). The NSIWM aims to increase recycling to 80% by 2030 (Conrad Prabhu, 2024a).

Private companies like Evergreen Gulf Recycling HUB, Recycling Services LLC, and Averda Environmental Services LLC have invested in recycling infrastructure and technologies. However, Oman's recycling industry faces challenges such as contamination of recyclable materials, inadequate infrastructure, and low public participation rates (Alwahaibi & Al Muslahi, 2024).

To address these issues, the government has implemented regulatory frameworks and policies, including EPR policies, tighter environmental laws, and public awareness initiatives (Umar, 2022); (Arwa *et al.*, 2013). However, Oman's recycling performance still lags behind international and regional benchmarks. Germany and Sweden have achieved recycling rates exceeding 60% through strong government policies, public engagement, and advanced recycling technologies. The UAE, Saudi Arabia, and Qatar have made significant progress through waste management infrastructure and public awareness programs. Table 1 provides a comparative analysis of recycling practices in leading and regional countries, highlighting strategies that Oman can adopt to enhance its recycling performance.

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How to cite this article: Kulkarni, M.V., Vijayanand M., Mudassir, S., Tabook, S.B.A.B., Al-Hafeedh, M.H.A. (2025). An overview of wastepaper and carton recycling in Oman. *The Scientific Temper*, 16(spl-2):58-69.

Doi: 10.58414/SCIENTIFICTEMPER.2025.16.spl-2.10

Source of support: Nil

Conflict of interest: None.

Table 1: Comparative analysis of recycling practices in leading and regional countries

Country	Key Strategies	Results	References
Germany	- Extended Producer Responsibility. - Comprehensive waste segregation at the source. - Strict penalties for non-compliance.	- Recycling rate > 65%. - High public compliance with recycling guidelines.	(Chamberlan, 2023; Wilke, 2017)
South Korea	- Pay-as-You-Throw (PAYT). - National awareness programs. - Dedicated food waste recycling systems.	- Recycling rate > 50%. - Significant reduction in landfill use. - High public participation.	(How the Volume-Based Waste Fee Policy Increased Household Recycling Rates in the Republic of Korea (1995-2009), n.d.)
Sweden	- Waste-to-Energy (WtE). - Circular economy policies. - Deposit-refund schemes.	- Near-zero landfill use. - Efficient waste-to-energy conversion. - High beverage container return rates.	(Waste Recycling in Europe, 2023)
United Arab Emirates (UAE)	- Mandatory waste segregation in urban areas. - Investments in state-of-the-art recycling plants (e.g., Enviroserve). - Public-private partnerships (PPPs).	- Recycling rate ~28% for MSW. - Increased private sector involvement in recycling.	(UAE, n.d.); (Ali et al., 2022)
Saudi Arabia	- Circular economy initiatives targeting 81% landfill diversion by 2035. - Investments in modern recycling plants and WtE facilities. - National Recycling Centre (NRC).	- Recycling rate ~15%. - Reduced dependence on landfills in major urban centers.	(Circular Economy in the GCC, n.d.)
Qatar	- Waste segregation at the source. - Advanced material recovery facilities (MRFs). - Public campaigns like «Trash to Treasure.»	- Recycling rate ~20%. - Steady reduction in MSW sent to landfills.	(Zafar, 2018)
Kuwait	- Small-scale recycling programs. - Partnerships with international recycling companies. - Pilot projects for plastics and paper recycling.	- Recycling rate ~10%. - Slow progress but growing awareness among urban communities.	(Zafar, 2018)

Oman must enhance its recycling practices to meet its 2030 targets by investing in rural infrastructure, intensifying public awareness campaigns, introducing EPR frameworks for sustainable waste management, and strengthening regulatory enforcement. Addressing barriers to effective waste management and providing actionable solutions for the GCC region and beyond can significantly improve Oman’s recycling performance and contribute to global sustainability goals.

Materials and Methods

This study employs an extensive review of secondary data sources to assess wastepaper and carton recycling in Oman.

Data Collection

National Reports

Data from Be’ah and the NSIWM.

International Benchmarks

Reports from UNEP and the World Bank for global context. Academic and Industry Literature: Peer-reviewed studies and white papers on technology, economics, and policies.

Case Studies

Examples from Germany, South Korea, the UAE, and others to identify applicable lessons for Oman.

Data Analysis

Thematic Analysis

Identified challenges like infrastructure gaps and contamination.

Comparative Benchmarking

Evaluated Oman’s practices against global and regional leaders.

Validation

Cross-referenced findings with credible sources for consistency.

Limitations

This study uses publicly available data and excludes primary data collection. Future research could include stakeholder interviews and fieldwork for localized insights.

Results and Discussion

Current State of Wastepaper and Carton Recycling in Oman

Oman’s recycling sector is currently evolving, with growing initiatives aimed at enhancing waste management systems and boosting recycling rates. Although the country has made significant progress in recent years, it still faces various obstacles in reaching optimal recycling performance.

Waste Generation and Collection

Waste Generation Statistics

Oman generates approximately 2.4 million tons of municipal solid waste (MSW) annually, with paper and carton waste accounting for 25% (about 600,000 tons). Effective recycling practices could significantly divert these materials from landfills (Service, 2023b).

Sources of Wastepaper and Carton Waste:

Major sources of paper and carton waste include households, offices, businesses, educational institutions, and retail sectors. Urban centres like Muscat, Sohar, and Salalah contribute most due to high population density and economic activity (Zafar, 2022). Figure 1 below depicts the breakdown of wastepaper sources by sector.

Collection and Recycling Rates

Currently, Oman recycles only 12% of its paper and carton waste. Significant amounts are still landfilled or incinerated. Government entities like be’ah are addressing this by improving collection systems and investing in recycling infrastructure to increase these rates.

Recycling Facilities and Industry Players

Key Recycling Facilities: Oman has several facilities dedicated to recycling wastepaper and cartons, including:

Evergreen Gulf Recycling HUB

Specializes in paper and carton recycling, E-waste management, and battery lead recycling. It processes large

volumes of wastepaper into pulp for recycled products (Evergreen Gulf Recycling Hub, n.d.).

Recycling Services LLC

Handles collection and processing of wastepaper and carton, offering services to public and private sectors (Recycling Services L.L.C, n.d.).

Oman Environmental Services Holding Company (be’ah)

Established in 2007 to implement the National Strategy for Waste Management, be’ah focuses on efficient resource use, infrastructure development, and sustainable integrated waste management (Barua, 2024).

Apex Media

Operates a recycling initiative in collaboration with over 560 organizations, such as Bank Muscat, HSBC, Central Bank of Oman, Bank Dhofar, schools and universities, Khimji Ramdas, Mall of Oman, Oman Air, OIFC, Omantel, etc., collecting newspapers, magazines, office papers, and cartons for recycling. Co-branded recycling boxes are available, promoting corporate social responsibility. (Muscat Daily, n.d.).

Processing Capacity and Technology

Oman’s current recycling capacity for paper and carton is approximately 190,000 tons annually, a fraction of the total waste generated. Increasing recycling rates requires investment in advanced sorting and processing technologies (Conrad Prabhu, 2024b).

Economic Impact of Recycling Industry

Recycling initiatives in Oman contribute to environmental sustainability while providing significant economic and social benefits.

Job Creation

The recycling industry has created over 300 direct and 500 indirect jobs, particularly benefiting less urbanized areas. With 2.4 million tons of recyclable waste generated annually, the Oman Investment Authority (OIA) estimates recycling could create over 2,300 additional jobs (Conrad Prabhu, 2023).

Cost Savings

Recycling reduces reliance on landfills, lowering costs for construction, maintenance, and environmental remediation. For instance, be’ah has reported substantial savings by diverting recyclables to processing facilities.

Revenue Generation

The sale of recycled materials, like paper pulp, could generate up to OMR 530 million annually, boosting national revenue (Service, 2023a)

Environmental Cost Reductions

Recycling minimizes greenhouse gas emissions and conserves natural resources by reducing dependence on raw material extraction, aligning with Oman’s climate goals.

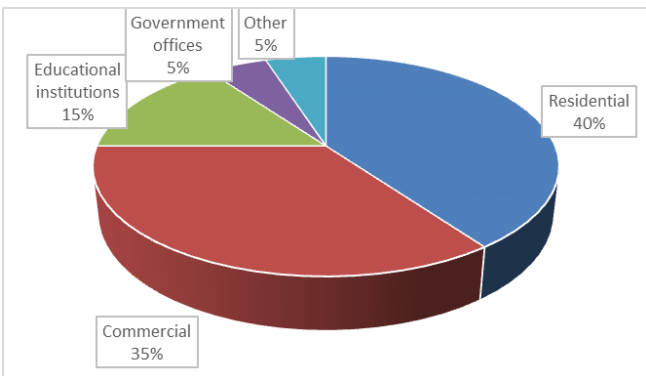


Figure 1: Breakdown of wastepaper sources by sector

Challenges and Areas for Improvement

Despite the positive impact of recycling initiatives, several challenges remain:

Contamination of Recyclables

Contaminated materials reduce the quality and economic viability of recycled products while increasing processing costs. Improved waste segregation at the source through education and infrastructure development is critical (Taha et al., 2004; Hajam et al., 2023).

Limited Reach in Rural Areas

While mobile recycling units provide some access, many remote areas still lack recycling facilities. Expanding programs to underserved regions is essential for effective waste reduction nationwide (Al-Mahrouqi & Victor, 2017; Conrad Prabhu, 2020a).

Sustaining Public Participation

Long-term public engagement in recycling requires continuous community outreach, adaptive strategies, and incentives to maintain motivation (Hakam, 2023).

Impact of Recycling Initiatives on Waste Reduction

Recycling initiatives in Oman have significantly reduced waste sent to landfills, particularly wastepaper and carton, through programs led by government entities like be’ah and private sector players such as Evergreen Gulf Recycling HUB and Recycling Services LLC (Conrad Prabhu, 2024a; Mohammed Al-Harthy, 2016). This section examines the impact of these recycling initiatives on waste reduction, highlighting key achievements, challenges, and areas for future improvement.

Reduction of Waste Sent to Landfills

Recycling initiatives in Oman have significantly reduced wastepaper and carton disposal in landfills, alleviating environmental degradation and extending landfill lifespans.

Data Insights

Figure 2 highlights four key economic metrics measured in millions of Omani Rial (OMR).

Future Value of Recycled Products

21.7 million OMR, indicating substantial potential for economic growth with expanded recycling efforts.

Exported Waste

7.7 million OMR, reflecting Oman’s current reliance on exporting recyclables due to limited local processing capacity.

Locally Recycled Waste

0.8 million OMR, showcasing underutilized domestic recycling capabilities.

Total Waste Produced

8.5 million OMR, representing the recyclable material available for processing.

These figures reveal opportunities to enhance local recycling, reduce export dependency, and maximize economic and environmental benefits. Investing in infrastructure, advanced technology, and policy development is essential to convert more waste into valuable products and foster a robust domestic recycling industry.

Environmental Benefits

Recycling reduces methane emissions from landfills, contributing to climate change mitigation. It also decreases dependence on raw materials, preserving forests and biodiversity while supporting ecological balance (Zuberi & Ali, 2015). Expanding these initiatives is crucial to maximize environmental and economic gains.

Regulatory Framework and Policies for Wastepaper and Carton Recycling in Oman

Oman has implemented key policies to enhance recycling rates and reduce landfill dependency, including the NSIWM and EPR. These initiatives reflect Oman’s commitment to sustainable waste management. A critical analysis of their strengths and weaknesses is essential to optimize outcomes.



Figure 2: Economic Indicators in the paper recycling sector (Sustainability Report, 2021)

Strengths of Oman's Policies

National Strategy for Integrated Waste Management (NSIWM)
Targets an 80% recycling rate by 2030 and promotes public awareness campaigns for waste segregation (Times News Service, 2024).

Extended Producer Responsibility (EPR)

Transfers waste management responsibility to producers, reducing municipal burdens ("Oman Is Getting Ready for the First ISWA World Congress in the Middle East," 2023).

Incentive Mechanisms

Financial incentives like tax breaks and subsidies encourage private sector investments (*Oman Announces 18 Investment Opportunities in Waste Management Projects*, 2022), (Conrad Prabhu, 2024b; *Oman Free Zones Attract Massive Green Industry Investments*, 2024).

Weaknesses

Implementation Gaps

Weak enforcement of EPR policies leads to inconsistent compliance (Ahlers *et al.*, n.d.).

Infrastructure Limitations

Recycling facilities are urban-cantered, leaving rural areas underserved and existing facilities overstretched (2023).

Public Participation

Campaigns have not yet achieved widespread behavioural change, especially in rural areas ("Environment Authority

Launches Green Initiative to Achieve Environmental Sustainability in Musandam," 2023),

Data Gaps

Insufficient monitoring and reporting mechanisms hinder policy evaluation and improvement.

Comparative Analysis with GCC and Global Leaders

Oman's recycling policies can be contextualized by comparing them to those of GCC countries and global leaders like Germany. Table 2 summarizes differences in policy enforcement, public engagement, and infrastructure support.

Key Comparisons

Germany

Employs strict enforcement of EPR policies with penalties, ensuring high compliance (*Waste and Recycling*, 2024).

Lesson for Oman

Strengthening EPR enforcement can enhance recycling rates.

United Arab Emirates (UAE)

Utilizes Public-Private Partnerships (PPPs) to develop advanced recycling infrastructure (Maryam, 2024).

Lesson for Oman

Investing in PPPs can improve infrastructure, particularly in underserved areas.

Table 2: Comparative analysis of regulatory frameworks

Policy Aspect	Oman	Germany	UAE	Saudi Arabia	Qatar	Kuwait
Policy Enforcement	Limited enforcement of EPR policies.	Strict enforcement with penalties (<i>Waste and Recycling</i> , 2024).	Collaborations through PPP frameworks (Maryam, 2024).	Gradual implementation of recycling mandates (<i>Roadmap for Sustainable Waste Management in Saudi Arabia</i> , n.d.).	Limited enforcement of recycling rules (Naveed, 2024)	Minimal enforcement and oversight (Al dababseh, n.d.).
Public Engagement	Public awareness campaigns in progress.	High public awareness and participation.	Incentive-driven public campaigns (<i>UAE Highlights New Investment Incentives & Opportunities in Its Vital Sectors in Light of 'Projects of the 50,'</i> n.d.)	Moderate awareness programs, primarily urban-focused (Al mulhim & Abubakar, 2021)	Growing awareness, but low participation (Clarke <i>et al.</i> , 2017)	Low public participation and engagement (Al Mansoor, 2020).
Infrastructure Support	Urban-focused recycling infrastructure.	Comprehensive across urban and rural.	Focused on urban areas with PPP support.	Expanding waste management facilities (<i>Waste & Recycling Industry at the Forefront of Saudi's Sustainability Efforts</i> , n.d.)	Limited infrastructure beyond urban centers.	Underdeveloped recycling infrastructure.

Saudi Arabia

Implements circular economy initiatives via the National Recycling Centre (NRC), aiming for 81% landfill diversion by 2035.

Lesson for Oman

Establishing centralized oversight bodies like the NRC can enhance policy execution.

Qatar

Focuses on public engagement with programs like “Trash to Treasure” and expands infrastructure with Material Recovery Facilities (Kilani, 2023)

Lesson for Oman

Combining public awareness with infrastructure investments can boost recycling outcomes.

Kuwait

Limited to pilot recycling programs and international partnerships with minimal enforcement (*Kuwait National Development Plan 2020-2025*, n.d.)

Lesson for Oman

Scaling pilot programs into full initiatives could increase public participation.

Recommendations for Policy Enhancement

Strengthen Enforcement

Introduce financial penalties for non-compliance with waste segregation and recycling mandates.

Expand Infrastructure

Build localized recycling hubs in rural and underserved areas to ensure equitable access to recycling facilities.

Promote Public Engagement

Combine financial incentives, such as deposit-refund systems, with targeted education campaigns to encourage behavioural change.

Invest in Data Systems

Establish robust data collection and reporting frameworks to evaluate policy impacts and adjust strategies as needed.

Adopt Proven Models

Tailor successful global policies, such as Germany’s EPR and South Korea’s VWF, to Oman’s specific cultural and economic context.

Challenges in Wastepaper and Carton Recycling in Oman

Despite progress in waste management infrastructure, several challenges hinder the effectiveness of wastepaper and carton recycling in Oman. These include gaps in public participation, infrastructure, and material quality, which need addressing to improve recycling rates and achieve sustainability goals.

Lack of Public Awareness and Participation

Limited Understanding of Recycling Benefits: Many residents and businesses lack awareness of recycling’s environmental and economic advantages. Surveys by be’ah show only 35% of households consistently segregate recyclables (Sustainability Report 2021, 2021).

Cultural and Behavioural Barriers

Cultural attitudes, perceived inconvenience, and skepticism about individual impact discourage recycling efforts. Tailored educational campaigns are needed to overcome these barriers.

Insufficient Educational Outreach

Current programs, like school initiatives and workshops, are not widespread. Expanding efforts, especially in rural areas, is crucial to boosting participation (*Community Outreach*, n.d.).

Income-Based Awareness

Research indicates that awareness of municipal solid waste segregation increases with household income. The highest awareness is among those earning 800–1000 OMR, while lower-income groups show less awareness as seen from Figure 3 (Umar, 2022)

Inadequate Recycling Infrastructure

Oman faces significant challenges in wastepaper and carton recycling due to inadequate infrastructure, including insufficient facilities, collection systems, and transportation networks, particularly in rural and remote areas (Mohammed Al-Harthi, 2016).

Limited Number of Recycling Facilities

facilities capable of processing wastepaper and carton are primarily located in urban centres like Muscat, Sohar, and Salalah. This urban focus leaves rural areas underserved,

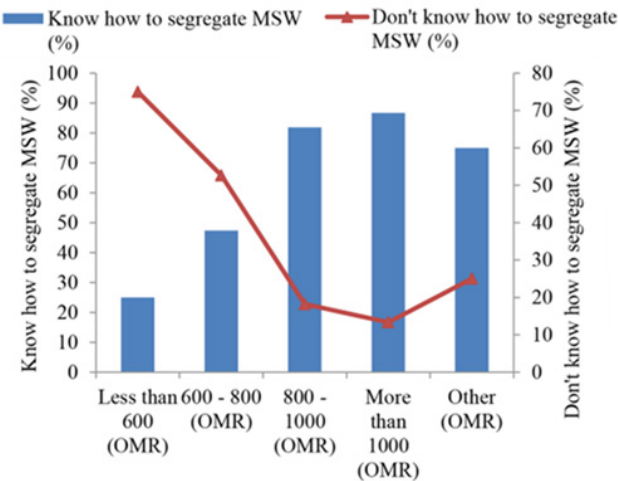


Figure 3: MSW Generated by Different Households (Umar, 2022)

limiting the collection and processing of recyclables from these regions (*Recycling Services L.L.C*, n.d.).

Insufficient Collection Systems

Recycling collection systems lack designated bins and reliable services, especially in less populated areas. Consequently, recyclables are often mixed with general waste and landfilled (Mohammed Al-Harthy, 2016). To address this, be'ah is piloting Mobile Recycling Units in South Al Batinah, featuring color-coded compartments for various waste types. These units aim to improve access to recycling services in underserved regions (Conrad Prabhu, 2020b)

Logistical Challenges in Transportation

High costs and difficult terrain hinder the transportation of recyclables from remote areas to facilities, further reducing recycling efficiency.

Quality of Recycled Materials and Contamination Issues

Contamination of recyclable materials is a major challenge that impacts the quality, economic viability, and efficiency of recycling processes in Oman.

Key issues

High Contamination Rates

Up to 30% of wastepaper and carton collected for recycling is contaminated, significantly reducing the quantity of usable material and driving up processing costs. Contaminated recyclables require additional sorting and cleaning, making recycling economically unfeasible in some cases (Sustainability Report 2021, 2021).

Lack of Effective Waste Segregation at Source

Ineffective segregation at the source is a primary cause of contamination. Households and businesses often fail to separate recyclables from other waste streams, leading to mixed waste that complicates recycling processes. Education and infrastructure development are essential to address this issue (Okedu et al., 2022).

High contamination levels increase operational costs for recycling facilities due to additional labour and equipment needed for sorting and cleaning. This reduces overall efficiency and deters investment in the recycling sector (Kutty, 2017).

Economic and Market Challenges

Oman's wastepaper and carton recycling industry faces several economic and market challenges that hinder its growth and sustainability.

Key Challenges

Volatile Market Prices

Prices for recycled materials, including paper and carton, fluctuate significantly due to global market dynamics and

supply-demand imbalances. These fluctuations make it difficult for recycling companies to maintain profitability, especially during low-price periods (*The Volatile Global Recycling Market*, 2023).

Limited Domestic Demand

The demand for recycled paper and carton products in Oman is low, as businesses and consumers often prefer virgin materials due to perceptions of quality or availability. Expanding the market through government incentives and public awareness campaigns is essential to increase acceptance of recycled products.

High Operational Costs

Collecting, sorting, and processing recyclables is expensive, particularly in remote areas or regions with limited access to advanced recycling technologies. These costs deter investment in the recycling sector and restrict program expansion.

Regulatory and Policy Challenges

Despite advancements in Oman's recycling framework, several policy challenges hinder the effectiveness of waste management efforts.

Key Challenges

Need for Stronger Enforcement

Existing regulations for recycling and waste segregation are inconsistently enforced. Strengthening enforcement mechanisms is crucial to improving compliance, increasing recycling rates, and reducing contamination.

Gaps in Policy Implementation

Rural and remote areas often lack the resources and support needed to implement recycling policies effectively. Expanding infrastructure and ensuring equitable application of policies across all regions are necessary to close this gap.

Limited Business Incentives

Current incentives, such as tax breaks and subsidies, are inadequate to drive substantial investment in recycling infrastructure. Enhancing these incentives could encourage more businesses to participate in recycling efforts and support industry growth.

Technological Challenges

Technological limitations hinder the efficiency and effectiveness of Oman's recycling programs.

Key Challenges

Lack of Advanced Recycling Technologies

Many recycling facilities in Oman still use outdated technologies and rely on manual sorting processes, which lower operational efficiency. Adopting advanced technologies, such as automated sorting systems and high-

efficiency pulping machines, can improve recycling rates and reduce contamination (Okedu et al., 2022).

Need for Research and Innovation

The recycling sector requires increased research and innovation to develop technologies capable of managing diverse materials and enhancing recycling outcomes. Encouraging innovation through research grants and collaborations with academic institutions can drive technological advancements and address existing limitations (Mashudi et al., 2023).

Potentials of Wastepaper and Carton Management in Oman

Wastepaper and carton management in Oman presents significant opportunities for environmental sustainability and economic development. Growing awareness of waste's environmental impact and a commitment to sustainable practices position Oman to enhance its recycling efforts.

Environmental Benefits and Sustainability

Reduction of Landfill Waste

Diverting wastepaper and carton from landfills reduces waste volume, extending landfill lifespan, decreasing environmental degradation, and lowering management costs. Enhanced recycling could reduce landfill waste by up to 80% by 2030, alleviating pressure on waste infrastructure.

Lower Greenhouse Gas Emissions

Recycling reduces emissions from waste decomposition and new paper production. One ton of recycled paper saves 17 trees, reduces car-equivalent carbon emissions for a month, and conserves water and energy, contributing to climate change mitigation (Robinson, 2023).

Conservation of Natural Resources

Recycling reduces the need for raw materials like wood and water, protecting forests and biodiversity. Oman's efforts support regional and global sustainability goals by conserving vital natural resources (Paper Recycling: How Does It Help the Environment?, 2024).

Economic Opportunities

The wastepaper and carton management sector presents numerous economic opportunities for Oman, ranging from job creation and economic diversification to the development of new industries and markets.

Key Opportunities

Job Creation and Economic Growth

Recycling programs can generate jobs in waste collection, sorting, processing, and facility operations. Expanding recycling infrastructure could create over 1,000 direct and indirect jobs, particularly benefiting regions with limited

economic activities. This growth contributes to economic expansion and supports local livelihoods.

Development of New Industries

Recycling can stimulate industries related to manufacturing recycled products, developing recycling technologies, and offering related services. This aligns with Oman's economic diversification goals, reducing dependence on oil and gas revenues while fostering sustainable economic growth.

Attraction of Investment and Partnerships

Improved recycling practices and infrastructure can attract domestic and foreign investment. Public-Private Partnerships (PPPs) are pivotal, exemplified by be'ah's collaboration with Tialoc and Al Ramooz National in developing an industrial waste treatment facility in Sohar Free Zone (Projects, 2024). Such initiatives enhance Oman's reputation as a leader in sustainable waste management.

Technological Advancements and Innovation

Technological advancements play a pivotal role in improving recycling rates, reducing contamination, and enhancing material recovery. While Oman faces challenges such as limited access to advanced systems, high costs, and inadequate expertise, adopting innovative solutions can help overcome these barriers. Table 3 highlights technologies with potential for Oman:

Addressing Challenges and Implementation

While these innovations offer solutions to Oman's recycling challenges, barriers like high initial costs, limited technical expertise, and infrastructure gaps remain significant.

Overcoming Costs

Government incentives and public-private partnerships (PPPs) can reduce financial burdens.

Capacity Building

Training programs and collaborations with academic institutions can address skill shortages.

Public Awareness

Campaigns can mitigate opposition to technologies like WtE and foster public support.

Strategic investments and stakeholder collaboration are crucial for unlocking the full potential of these advancements, enabling Oman to achieve its sustainability goals and establish itself as a leader in waste management innovation.

Research and Development Opportunities

Oman has the potential to become a hub for innovation in recycling technologies and sustainable waste management by fostering collaboration among academic institutions, industries, and international organizations.

Table 3: Technological innovations in recycling – applications, feasibility, and challenges

Technology	Example	Impact	Feasibility in Oman	References
Advanced Sorting Systems	Optical sorting systems in Germany and Sweden use AI-driven cameras to sort recyclables by type (e.g., paper, plastic, metal).	- Increases sorting speed. - Reduces contamination. - Enhances recycling efficiency.	- High initial costs (~\$1–3M per facility). - Viable in urban centers (Muscat, Salalah). - Requires skilled operators.	(European Environment Agency, n.d.)
Waste-to-Energy (WtE)	Sweden incinerates non-recyclable waste to produce electricity and heat, achieving 99% landfill diversion.	- Reduces landfill use. - Generates renewable energy. - Decreases greenhouse gas emissions.	- High setup cost (~\$120M per plant). - Public resistance due to emissions concerns. - Suitable for urban areas with high waste generation.	(Waste To Energy Technology, n.d.)
IoT in Waste Management	South Korea employs IoT-enabled smart bins to monitor waste fill levels, optimizing collection routes and reducing operational costs.	- Prevents bin overflow. - Cuts collection costs. - Improves recycling efficiency.	- Affordable (~\$100–500 per bin). - Scalable for urban areas. - Requires IoT integration with existing waste systems.	(IoT - Collection and Sorting, n.d.), ("How Seoul Used the IoT to Improve Waste Management and Collection," 2017)
High-Efficiency Pulping Machines	India uses advanced pulping machines to recycle wastepaper into high-quality pulp with minimal water and energy usage.	- Enhances quality of recycled products. - Reduces water and energy consumption. - Cuts operational costs.	- Cost-effective (~\$50,000 per machine). - Ideal for Oman's growing paper industry. - Easy to integrate with existing facilities.	(The Pulp and Paper Industry, 2019), (Tamboli et al., 2022)
Automated Material Recovery Facilities (MRFs)	UAE's Enviroserve processes over 100,000 tons of recyclables annually using automated sorting and recovery technologies.	- Increases processing capacity. - Improves material recovery rates. - Boosts recycling profitability.	- Moderate to high costs depending on facility size. - Public-private partnerships can facilitate adoption. - Supports Oman's circular economy goals.	(The Recycling Hub' Is a Game Changer, 2019)

Key Initiatives

MOHERI Research Grants

The Ministry of Higher Education, Research, and Innovation (MOHERI) supports waste management research through the Block Funding Program (BFP), offering grants:

Undergraduate Research Grant (URG)

1,500 OMR.

Graduate Research Grant (GRG)

3,000 OMR, for Master's degree holders.

Research Grant (RG)

20,000 OMR, reserved for PhD candidates. Projects aligned with Oman Vision 2040, including waste management innovations, are prioritized (Health, n.d.)

University of Technology and Applied Sciences (UTAS)

Awards up to 1,000 OMR for projects focusing on waste innovation and sustainability (UTAS, 2023)

Digital Solutions and Smart Waste Management

The integration of digital technologies like IoT sensors, data analytics, and smart waste systems can optimize waste management processes:

Efficiency Gains

Digital solutions streamline waste collection, sorting, and recycling, reducing operational costs and increasing effectiveness.

Enhanced Data Utilization

Smart systems enable real-time monitoring and analytics, improving decision-making and resource allocation (Alwahaibi & Al Muslahi, 2024).

Investing in R&D and adopting digital technologies will not only advance Oman's waste management sector but also position the country as a leader in sustainable innovation.

Social Impact and Community Engagement

Effective wastepaper and carton management fosters community engagement, promotes environmental stewardship, and enhances the quality of life. Recycling initiatives encourage sustainable practices through educational programs, awareness campaigns, and community-based efforts.

Proper waste management reduces pollution, improves air and water quality, and minimizes health risks, creating cleaner environments. Recycling also decreases landfill use and open burning, directly benefiting public health.

Community-driven recycling programs empower local groups, schools, and organizations, fostering social cohesion and a sense of responsibility. These initiatives build a more engaged and environmentally conscious society, promoting collective action for sustainability.

Potential for Policy Development and Leadership

Oman can become a global leader in sustainable waste management by implementing innovative policies and frameworks. Key measures include offering incentives for businesses and households, adopting EPR, and encouraging sustainable product design. Setting ambitious recycling targets, creating innovative waste solutions, and fostering international collaborations can strengthen Oman's global sustainability reputation and establish it as a model for sustainable waste management practices.

Conclusion

Oman's wastepaper and carton recycling plays a vital role in its waste management and sustainability goals. Significant progress has been made in infrastructure development, public awareness, and regulations. Key entities like Be'ah and private firms have improved recycling rates and reduced landfill use. However, challenges remain, including low public awareness, inadequate infrastructure, contamination, market constraints, technological gaps, and regulatory shortcomings. Addressing these requires public education, facility modernization, stricter regulations, and economic incentives. Investment in advanced technologies and innovation is essential to enhance operations. Future research should focus on cost-effective technologies, public participation behaviours, and the lifecycle benefits of recycled materials. Insights into circular economy integration, informal recycling sector formalization, and climate change mitigation potential are crucial. By tackling these issues and seizing opportunities, Oman can achieve its waste management goals and foster a more sustainable, greener future.

Acknowledgments

The authors thank the University of Technology and Applied Sciences – Oman for funding the project titled "Recycling of Cardboard and Paper into a Usable Product Using 3D Printing and Hand Layup Methods" under the Internal Funding Program.

Source of Support

University of Technology and Applied Sciences - Oman

Conflict of Interest

The authors declare that they have no conflicts of interest to disclose.

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