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Logistics and Sustainability in E-Waste Management: A Case Review from Oman

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Abstract

This research article presents broad-based review on e-waste management at the Sultanate of Oman. It describes the types and practices of handling e-waste. The article also explores the collection and transportation of e-waste from various companies to the recycling hub. In addition, this article focuses on the opportunities for sustainable e-waste management including environmental challenges and studies relevant literature on handling logistics routing and fixing up warehouses in a particular city.

Keywords: *E-Waste Management, Sustainability, Environmental Impact, Logistics*

Introduction

E-waste is a basic requirement of ecologically sustainable development of Oman. In an electronic-driven world, the use of electricity and electronic items is inevitable. The advancement of technologies is rapidly evolving while discarded e- wastes are dumped to a so called “recycle bins”. When these wastes are treated as scraps, the components are more hazardous to the environment and consider as health risks since they release toxic elements that could contaminate the environment and the population. Likewise, burning out e-waste in open places is another dangerous issue. This could highly pollute the air and increase the chances of global warming (7). A generic e-waste management value chain in a developing country, the e-waste material flow is given below. It gives the general idea of generic flow e-waste material. Some countries with fewer resources lack waste disposal laws, enforcement, and trash treatment. As a result, the informal sector in those nations frequently handles e-waste in less-than-ideal methods. To treat e-waste in an environmentally-sound manner, it needs to be regulated. A generic e-waste management value chain in developing countries involves both informal and formal stakeholders. Waste-to-energy technologies and landfill methane reduction techniques help to mitigate climate change by lowering greenhouse gas emissions. Furthermore, public health is greatly impacted by efficient waste management. The assurance of proper trash collection, its treatment, and disposal reduces the risk of vector-borne, aquatic illnesses, and respiratory conditions connected with inappropriate waste management.

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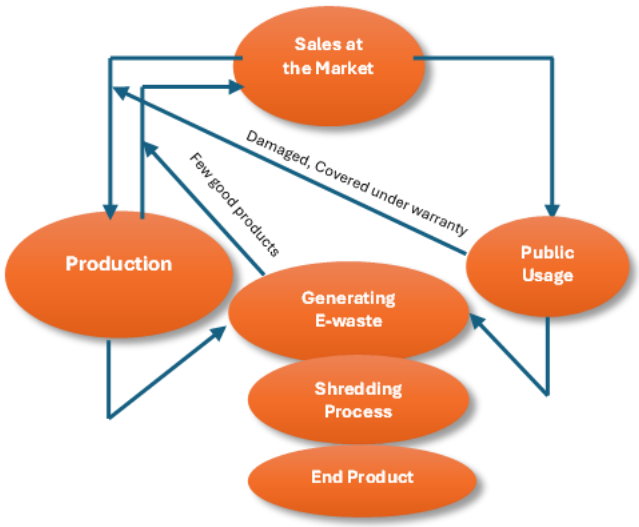

Fig. 1: E-Waste Management

In general, it is impossible to exaggerate the importance of efficient waste management for both public health and environmental sustainability. Sustainable waste management techniques set the stage for a better and more sustainable future for the Sultanate of Oman and its communities by lowering pollution, preserving resources, preventing climate change, and protecting public health.

Overview of E-waste Management

Every year, Oman produces a total of over 2 million tons of hazardous garbage, which includes e-waste. This garbage becomes larger as Oman's population saw its growth and the widespread utilization of technology. In the past, landfills received more than 90% of waste, particularly e-waste, which posed environmental risks because of potentially harmful substances like lead and mercury.

Through the Oman Environmental Services Holding Company (be'ah), the government is modernizing its waste management initiatives. These efforts, guided by the National Waste Management Strategies, aim to lessen the reliance on landfills and boost recycling rates through industrial development. Accordingly, the government is also considering investing in recycling infrastructure via public-private partnerships (PPP's) that follows strict regulations for the disposal of both hazardous and commercial waste, thus, leads the government to focus on ongoing projects like the conversion of waste into green energy.

Salalah has the largest storage facility in Oman with a capacity of 20,000 tons per year. This hub is equipped with on-site hard drive crashes and an AI-driven sorting system to ensure data protection. It processes a wide range of electronics, including TVs, computers, cell phones, and other electrical devices, to recover valuable materials such as PCBs, polymers, and minerals. Other participants in the Omani e-waste recycling sector also focus on securing data deletion and recycling.

In general, significant progress in waste management is being driven by new technologies and a shift towards a circular economy. Smart waste management is being implemented through IoT-enabled bins, which optimizes the collection of electronic waste by signaling when it is full. Additionally, AI-powered systems are being developed for more efficient waste separation, while industrial waste is being reduced using baling equipment and biological processing. Despite these advancements, several challenges persist, including a general lack of public awareness regarding proper e-waste disposal and the need for more recycling infrastructure, especially in remote areas. As a result, the enforcement of evolving waste segregation laws remains a continuous hurdle.

Types of E-waste

Electronic garbage, or "e-waste," is an important threat to the environment in Oman. The problem is caused by a variety of discarded gadgets. Below is a summary of the primary categories of e-waste that are frequently encountered in the Sultanate:

Massive Residential Electronics: The following are Oman's primary e-waste sources. Televisions (16,580 tons year), air conditioners (16,350 tons annually), washing machines (11,470 tons annually), refrigerators (18,330 tons annually), and microwave ovens**.** (1)

***Personal and Office Electronics*:** These include smaller but no less important forms of e-waste, such as phones (900 tons annually), laptops, monitors, keyboards, printers, hard drives, music systems, fluorescent lights, and personal computers (6,820 tons annually). (2)

***Cables and Electrical Components*:** Motors, cables, wires, and printed circuit boards (PCBs) are also frequently discarded and processed for valuable components like metals and polymers.

***Data-Sensitive Devices*:** Because of data privacy issues, devices like hard disks are handled with extra caution. Certain establishments provide Certificates of Destruction and on-site shredding.

Companies' Practices on Handling E-waste

Under the guidance of both government legislation and private initiatives, businesses in Oman are progressively implementing sustainable and organized methods to handle electronic trash, or "e-waste". Many businesses are partnering with specialized facilities to ensure the proper disposal of electronic waste. These processing centers, some of the largest in the region, utilize advanced technologies like AI-enabled systems for waste segregation at a molecular level. They also offer secure data destruction services, including on-site mobile shredding, to protect sensitive information from being compromised. The goal is to recover valuable materials such as PCBs, aluminum, and various metals, transforming waste into resources and promoting a circular economy.

Far beyond recycling, other firms are also involved in the e-waste management ecosystem. Some provide secure data recovery and destruction services, while others, primarily in the IT sector, have incorporated eco-friendly procedures into their operations. These practices often involve responsibly managing end-of-life electronics and ensuring they are handed over to certified recyclers. This collaborative approach involves both specialized recyclers and responsible business establishment owners who undertake crucial sustainable tasks in minimizing the environmental impact of electronic waste.

The Environment Authority in Oman oversees significant government initiatives for waste management (4,5,6). One of its key tools is the National Garbage Register of Oman, which tracks the volume and origin of waste from individuals, businesses, and government entities. This system helps facilitate the registration of recycling facilities, carriers, and waste collectors, while also monitoring licensing and compliance. The primary objective of the register is to prevent unauthorized or random waste dumping.

In addition to these tracking initiatives, Oman has a clear regulatory framework to guide waste management. Businesses are required to comply with Royal Decree which mandates that all waste-generating operations must obtain environmental permits. Furthermore, the Oman actively promotes the principles of reduce, reuse, and recycle in line with the broader sustainability goals outlined in Vision 2040.

E-waste Generation and its Composition

Oman, like other countries, produces a substantial amount of electronic garbage because of rapid technological development. Oman's rapid urbanization and industrial expansion have resulted in an increase in the use of electrical and electronic equipment. According to the Global E-waste Monitor's 2020 study, Oman generates a substantial amount of e-waste each year, estimated to be around 69 kilotons. Oman's e-waste creation per capita is predicted to be roughly 15.8 kg, and it is expected to rise as technology penetration and consumer electronics demand increase. E-waste generation in Oman more than doubled between 2013 and 2018, rising 146% from 54,148 tons to 133,304 tons (4,5,6). This expansion directly adds to rising volumes of e-waste, one of the fastest-growing waste streams globally and regionally. In Oman, bulky household items such as refrigerators, washing machines, televisions, air conditioners, and personal computers are the most common producers of electronic trash. Because of their shorter lifecycles and frequent replacement rates, mobile phones and laptops account for a sizable amount of e-waste production. TVs, monitors, printers, batteries, and appliances are all common types of e-waste. If not correctly managed, e-waste contains toxic compounds that can endanger the environment and humans.

However, international studies and regional analyses show that e-waste in the Middle East and around the world contains valuable materials such as iron and steel (50% or more by weight), plastics

(21%), non-ferrous metals (such as copper, aluminium, and precious metals - gold, silver, platinum, palladium), and hazardous components such as lead, mercury, cadmium, and brominated flame retardants. Oman generates more than 2 million tons of municipal solid waste each year, with more than 90% ending up in landfills (4,5,6).

Collection and Transportation of E-waste

In Oman, the management of electronic waste (e-waste) is spearheaded by the government-owned holding firm “be'ah”, which collaborates closely with several private sector partners various recycling hub in Oman. This collaboration utilizes a strong infrastructure that combines specialized collection services, drop-off programs, and modern smart technology to ensure effective collection and transportation of electronic trash across the country.

The collection of electronic waste (e-waste) in Oman is facilitated through a well-structured system designed to promote responsible disposal and recycling (8). Central to this system are various collection points strategically placed to ensure ease of access for the public. These include municipal waste collection centers, designated collection bins located in high-traffic areas such as shopping malls, business districts, and government offices, as well as dedicated e-waste recycling programs managed by private entities, including recycling companies and non-governmental organizations (NGOs).

To complement these collection efforts, ongoing public awareness campaigns play a vital role in educating individuals, businesses, and organizations about the importance of properly recycling e-waste. These initiatives emphasize the environmental and health benefits of safe disposal and encourage the public to utilize approved collection points rather than discarding electronic devices with general waste.

In addition, corporate responsibility forms a key pillar of the e-waste management framework. Many businesses are either encouraged or mandated to adopt strategies that facilitate the collection of discarded electronics from employees and customers. Some private firms enhance participation by offering incentive-based collection systems, providing convenient drop-off locations for consumers to return their old devices, thereby fostering a culture of sustainability and environmental stewardship.

The Environment Authority (EA) requires all entities involved in waste collection and transportation (3), including e-waste, to obtain the appropriate licenses. This involves registering with the National Waste Management Registry System and following requirements for the safe handling and storage of hazardous materials.

Once collected, e-waste is safely transported to central processing facilities or recycling sites. This logistics chain begins with e-waste segregation, which separates hazardous items like batteries, mercury, and lead from non-hazardous components such as plastics and metals. Following segregation, garbage is safely packaged, with hazardous materials contained in specially constructed containers to avoid leakage or contamination during shipment.

E-waste is often transported by specialized transport companies who are trained to handle hazardous items. These companies follow strict safety measures and international regulations, particularly those established by the Basel Convention to ensure safe and compliant transportation practices.

In Oman, e-waste transportation is primarily by road, with towns such as Muscat benefiting from well-established networks that enable the safe and efficient transit of electronic garbage to recycling facilities (8). For all cross-border exports, Oman adheres to international conventions and agreements that govern the movement of hazardous waste, assuring worldwide environmental protection and responsible waste management.

Different ways of e-waste disposal and its treatment

Numerous methods are adopted for proper disposal of e-waste that include the following:

Recycling components: An item which is discarded as e-waste may contain several miniature components which can be reused while building a new product. For example, electronic elements such as IC’s, microcontrollers, displays, capacitors can be reused as they have long lifespans. The motherboard of the equipment may be found faulty because of the failure of only a few components while the rest could be properly reused. The casing of all these components is usually made of ABS, fiberglass, carbon fiber or even plastic which can be easily dismantled and sent for recycling.

Incineration: This can be done under controlled conditions to generate huge amounts of heat energy which can be used for various industrial purposes and to reduce the volume by nearly 90%. Although done in restricted conditions, the residue generated can be highly toxic to the environment and the releases may contain pollutants which can contaminate air, soil and water.

Landfilling: High volumes of e-waste are used for landfill in large voids created by mining. These are covered by clay for extra protection from toxic gas generation with time and to seal radioactive compounds if any. Since these are deposited much deeper, it will not harm the surface vegetation.

Acid bath: E-waste components are directly submerged into strong acids which can extract some metals from them. This method is highly dangerous for the environment and not advised at all but unfortunately followed by informal warehouses or workshops.

Composting: This is a less common practice of composting biodegradable materials in e-waste using specialized facilities.

Donation: Reusable units can be donated to non-profit organizations in Third World countries. Equipment may be slightly outdated but can be really useful for training purposes.

Environmental Impacts & Community Awareness

Proper e-waste management can bring numerous benefits to the Omani community, not only in terms of environmental protection but also in economic growth, public health, and social development. One of the most significant advantages is the preservation of Oman's natural environment, which is central to the nation's identity and heritage. By managing electronic waste responsibly, harmful substances such as lead, mercury, and cadmium are prevented from leaching into the soil and water systems, thus protecting fragile ecosystems, agricultural lands, and water resources that many communities depend on. This, in turn, safeguards public health, as improper disposal of e-waste can release toxic fumes or chemicals that contribute to respiratory illnesses, neurological damage, and other long-term health problems (7).

Proper e-waste management also creates opportunities for economic diversification, which is a key pillar of Oman's Vision 2040. Recycling and recovery industries can generate new jobs for Omani youth, ranging from collection and sorting to advanced recycling technologies and research into sustainable materials. Moreover, recovering valuable materials like gold, copper, and rare earth elements from old electronics reduces the need for costly imports, saving the country money while also contributing to a circular economy. From a social perspective, community awareness and participation in e-waste initiatives can foster a stronger sense of environmental responsibility and shared commitment to sustainability, aligning with Oman's cultural values of stewardship of the land.

Schools, universities, and community organizations can use e-waste management projects as educational tools to promote innovation, entrepreneurship, and environmental literacy among young Omanis. Additionally, proper e-waste management helps Oman meet its international environmental commitments, enhancing its global reputation as a nation that values sustainability and responsible development. This can attract foreign investment, particularly from companies and industries seeking to partner with countries that prioritize green practices. On a practical level, reducing e-waste pollution lowers the burden on municipal waste systems and landfills, allowing local governments to allocate resources more efficiently to other public services.

Cleaner urban and rural areas also enhance the overall quality of life for citizens and support Oman's efforts to boost tourism, as visitors are drawn to destinations that demonstrate care for their natural and built environments. Furthermore, e-waste management encourages innovation as local entrepreneurs and researchers can develop new technologies and methods for recycling, repurposing, and reusing materials, turning potential environmental problems into opportunities for creativity and profit. In essence, the Omani community stands to gain a healthier environment, improved public well-being, new economic opportunities, greater global recognition, and a stronger culture of sustainability by adopting effective e-waste management practices. These benefits collectively contribute to building a resilient, prosperous, and environmentally conscious society that can face the challenges of modern technology while preserving the nation's unique natural and cultural heritage for future generations.

Conclusion

This comprehensive review of e-waste management in Oman clarifies on current practices and challenges followed here. This review spotlighted the increasing of e-waste in a direct proportional way

in all parts of Oman. The inspection of e-waste collection and logistics disclose the challenges on its efficiency, and framework. The conclusions drawn from this investigation highlight Oman's outstanding sustainable e-waste management techniques. It emphasizes how urgently better infrastructure, more funding for waste management systems, and regulatory changes are needed. Although this study offers insightful information about e-waste management in Oman, there are a few areas that need more research. This article can be extended to fixing up the warehouses in a different region to store electronic garbage before being transported. An extension of this study would be to upgrade facilities in a different industry to store electronic waste prior to transportation.

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