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Sustainable Digital Waste Management

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ABSTRACT
The world is experiencing significant electronicization, including digital transformation, and technologies are fundamentally changing the way we live, work, learn, socialize and do business. Many people own and use multiple electronic devices, and the increasing connectivity of urban and remote areas has led to an increase in the number of devices and objects connected to the Internet. Digital waste (**D- waste**)covers a wide range of products used by homes and businesses. It includes electrical appliances such as refrigerators, stoves, washing machines and hair dryers, as well as electronic devices such as mobile phones, wireless headphones and tablets. Today, a large part of the world is in the process of becoming electronic and digitally transformed, as electronic and digital technologies have profoundly changed the way we live, work, learn, socialize and do business. According to the latest global data, there are 108 mobile phone subscriptions for every 100 people. Well-structured planning with effective policy interventions are key to reducing d-waste by providing a framework to minimize d-waste generation and protect the environment. These plans can ensure proper disposal methods, public awareness, appliance repair and refurbishment, and recycling rates, with d-waste management monetizing the efforts of d-waste management initiatives.

1. INTRODUCTION

Dünya, dijital dönüşüm de dahil olmak üzere önemli bir elektronikleşme yaşıyor ve teknolojiler yaşam, çalışma, öğrenme, sosyalleşme ve iş yapma biçimimizi kökten değiştiriyor. Birçok kişi birden fazla elektronik cihaza sahip ve kullanıyor ve kentsel ve uzak alanların artan bağlantısı, İnternet'e bağlı cihaz ve nesne sayısında artışa yol açtı. Bu büyüme, Dijital Atık (**D-Atık**) miktarında eş zamanlı bir artışa neden oldu. Aynı zamanda, küresel D-atık toplama ve gerdönüşüm oranı bu büyümeyle aynı hızda ilerlemiyor.

With a growing global population, the world has seen an increase in the adoption of innovative technologies, and with each technological advancement, people are moving towards newer electronic devices, leading to the disposal of old electronic products [1]. D-waste generation has increased significantly over the last decade, driven by continuous technological [2]. According to Shittu et al. [3], global d-waste generation increased significantly in 2019, reaching 54 million tons [4].

Monitoring d-waste volumes and flows is important to assess developments over time, to set and evaluate targets, and to measure the extent to which electronics can help reduce the impacts of climate change and minimise resource scarcity. When used to increase sound collection and recycling, appropriate data and legislation can be extremely effective in accelerating environmental protection and retention of valuable materials. However, without a comprehensive and representative picture of the global d-waste challenge, the true extent of this waste stream and the negative externalities it creates will remain unknown. However, for industry and policy makers to truly benefit from the positive circular economy potential of the electronics sector, reliable data must be freely available to inform decision-making [5].

With the increase in technology use and dependence, D-waste generation globally has crossed the 65 billion tons mark, according to the Global D-waste Monitor 2024. D-waste is causing serious damage to the environment as it releases harmful toxic substances such as heavy metals, non-ferrous substances, microplastics, glass and

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others, causing serious impacts on the environment, including soil, water and air, raising concerns for health and ecosystem [6]. According to the latest report published by the Global E-waste monitor 2024, Europe is the largest producer of E-waste with 17.6 Kg per capita, followed by Oceania with 16.1 Kg and finally America with 14.1 Kg, as these are the most developed regions of the world with modern technology.

These developed continents and nations have improved the collection and recycling infrastructure. Global D-waste regulations are increasing in different countries and it has been stated that currently 72% of the global population is under the laws and policies of different nations aiming to reduce D-waste pollution. To address the increasing problem of D-waste, many developed nations have implemented comprehensive policies for D-waste management and these policies include the entire D-waste management process starting from collection, transportation, disposal and finally recycling of D-waste [7].

2. DIGITAL WASTE

2.1. What is Digital waste?

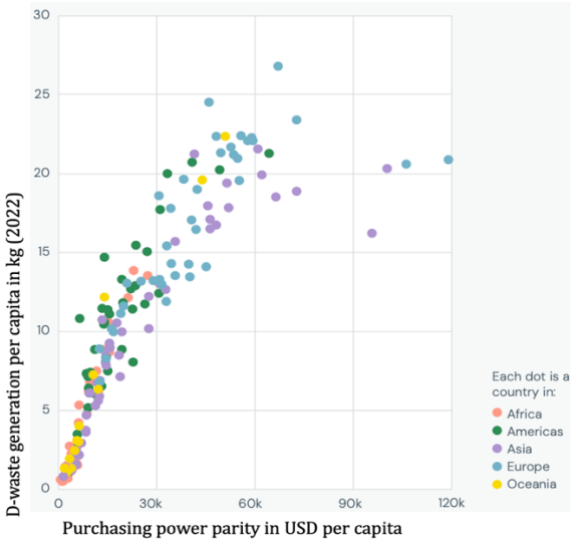
D-waste includes electrical appliances such as refrigerators, stoves, washing machines and hair dryers, as well as electronic devices such as mobile phones, wireless headphones and tablets. Much of the world is currently in the process of electronicisation and digital transformation, and electronic and digital technologies are fundamentally changing the way we live, work, learn, socialise and do business. According to the latest global data, there are 108 mobile phone subscriptions for every 100 people [8].

Image 1. D-waste

D-waste comprises a wide variety of products, each with its unique material content, form of disposal and recycling approaches, and each causing unequal harm to the environment and human health if not managed in an environmentally sound manner [9].

2.2. Regional Comparisons in D-waste Management

Income and purchasing power There is a link between a region's per capita purchasing power and the amount of D-waste it produces. Generally, higher-income regions tend to produce more D-waste because they consume more goods and have greater access to D-waste (Figure 1).

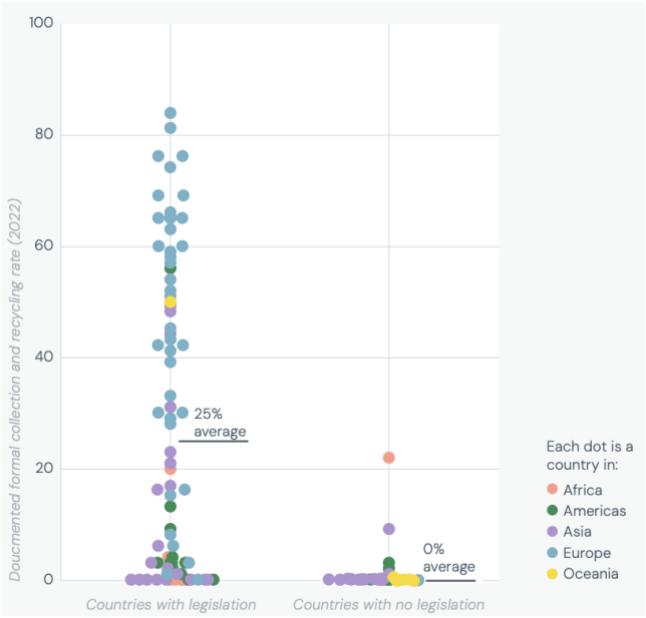


Source: The Global E-waste Monitor 2024 [10].

Figure 1. D-waste production and purchasing power by income status of countries

2.3. D-Waste Collected and Recycled by Regio

D-waste legislation and regulation In countries that regulate and enforce D-waste management through legally binding instruments, by setting collection and recycling targets, or by D-waste legislation or policies, the average documented official collection and recycling rate is 25%. In countries without such legislation, even in draft form, collection rates are equal to 0% (Figure 2). Comparisons also highlight differences in behaviour among citizens in different regions and subregions within a continent. In many low-income regions, the informal sector plays a significant role in D-waste management. While the contribution of the informal sector can be significant, it is often not reflected in official data or monitored by governments. Informal recycling often results in very low resource efficiency rates and therefore does not meet environmental or health and safety standards.



Source: The Global E-waste Monitor 2024 [10].

Figure 2. D-waste collected and recycled by region

3. DIGITAL WASTE AND SUSTAINABLE ENVIRONMENTAL IMPACT

3.1. Environmental Impact

Global digital waste (d-waste) generation is rapidly increasing due to advances in information and communication technology, artificial intelligence, and the widespread adoption of electronic devices, semiconductors, electric vehicles, and energy storage systems [11,12].

The environmental impact of improperly disposed of electronic devices is profound, affecting soil, air, and water, and contributing to global warming. When e-waste is dumped in landfills or improperly treated, toxic substances such as lead, mercury, and cadmium leach into the soil, contaminating the soil and rendering it unfit for agriculture. These hazardous substances can also leach into groundwater and pose serious risks to drinking water supplies and aquatic ecosystems.

Image 2. Digital waste and sustainable environmental impact

Air pollution is another major concern. Incineration of e-waste, a common practice in informal recycling operations, releases toxic fumes, including dioxins and other hazardous chemicals, into the atmosphere. These pollutants reduce air quality and can cause respiratory problems and other health problems in people living nearby. Furthermore, the decomposition of e-waste in landfills produces greenhouse gases such as methane and carbon dioxide, which contribute to global warming and exacerbate climate change. The cumulative effect of these environmental impacts highlights the urgent need for proper e-waste management and sustainable disposal practices.

This improper disposal of d-waste endangers ecosystems and human health, primarily due to hazardous components such as heavy metals or brominated flame retardants [13]. It is important to use environmentally friendly recycling technologies, as inadequate recycling contributes to environmental pollution. It is particularly important to remove hazardous substances from recycling processes and ensure their safe disposal in secure landfills [14]. Effective d-waste management is essential for environmental protection, resource saving, energy efficiency, waste reduction, and a sustainable circular economy.

3.2. Risks of sustainability and digitalization

Digitalization requires an increasing element of computers, data centers, mobile phones, crypto mining nodes, batteries and networks. In 2019, ICT generated a record 53.6 million metric tons of d-waste globally. These figures show that d-waste is the fastest growing household waste stream, with 17.4% of d-waste being collected and recycled, and only 78 countries have legislation to manage d-waste. Therefore, digitalization and the circular economy must be linked to ensure that the minerals used in technology production are traceable, recovered and recirculated (image 3).

Image 3. Digitalization

Computer hardware production accounts for 75% to 85% of the environmental impact of the digital world. Regulatory frameworks should be promoted to raise awareness of the circular

economy, product life cycle and sustainable purchasing behavior.

D-waste poses a significant challenge in the region, where there is little capacity to address the recycling challenge. In West Asia, d-waste is often disposed of using general waste, open dumps and open incineration. Disposal, fragmentation and recycling of d-waste through illegal or unofficial methods and methods that fall below international standards for d-waste management are the main reasons for the negative impact of d-waste on the environment [15].

Sustainability means that D-waste is managed in this way and has a low impact on the environment and human well-being. It also includes growth and reduced environmental impact, increased economic development and increased social well-being. Sustainable electronics means lower costs and increased life, meaning that electronics last longer and leftover parts are used for new electronics. Manufacturers implement a program so that consumers can easily recycle electronics and use recycled materials such as mercury, lithium and other chemicals that are rare earth minerals, reducing the cost of new electronics (Balkenende and Bakker, 2015).

4. Conclusion

Mountains of discarded electronics are not just an ugly sight; they are a ticking time bomb for our health and our planet. D-waste is the fastest growing waste stream, and the increasing population and the continuous increase in the production and disposal of electronics have led to a continuous increase in environmental problems. It can be stated that D-waste management can be effective by consuming electronics responsibly and reducing the improper disposal of these goods before their end-of-life scenarios. It is now equally important for governments to create better policies, technology companies to adopt greener technology, and people to make smart choices and recycle responsibly.

It is an inevitable fact that the use of electronic technologies in societies is increasing exponentially and has become an inseparable part of our lives. Most of them were unaware of the adverse effects on health and environment caused by improper disposal of d-waste. It can also be said that the participants had the least knowledge about government guidelines on d-waste disposal. Therefore, education on sustainable recycling and negative effects of d-waste is essential for people and awareness on proper disposal of e-waste is a need.

Conflict of Interest

No conflict of interest is declared by tehe authors. In addition, no financial support was received.

Author Contributions

Study Design, ND; Data Collection, ND; Data Interpretation, ND; Manuscript Preparation, ND; Literature Search, ND. Author has read and agreed to the published version of the manuscript.

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