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The new threat in electronic waste: Environmental burden of electronic cigarettes

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Abstract:

With the advancement of technology, the availability, variety, and use of electronic cigarettes have increased significantly. Recent studies on the potentially harmful effects of electronic cigarettes on health suggest that they are not considered less harmful or reliable than traditional cigarettes. It is known that the waste generated by the production, use, and disposal of conventional cigarettes is harmful to the environment and poses a significant burden. The environmental burden of electronic cigarettes, which contain many components such as batteries, heating coils, e-liquid, plastic cartridges, and microprocessors, is recognized as an emerging problem. The fact that waste from electronic cigarettes, which could become the cigarette butts of the future, is already appearing in garbage highlights the need for careful monitoring of the process and prompt action to address it. Scientific studies investigating the environmental impacts of electronic cigarette production, use, and disposal are limited. This study aims to reveal the environmental impacts of electronic cigarettes, which are predicted to become a significant public health problem, and examine these impacts in the context of the United Nations Sustainable Development Goals. A descriptive case study, a qualitative research design, was used for this purpose. The research revealed a minimal number of studies and limited evidence on the environmental effects of electronic cigarettes in the literature. It has been observed that both governments and manufacturers are delaying the fulfillment of their responsibilities regarding electronic waste disposal. Recommendations are provided for the measures governments should take to manage electronic cigarette waste before the problem becomes unavoidable.

Keywords:

Electronic cigarette, environmental pollution, health policy, tobacco product waste, vapes

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Introduction

The World Health Organization (WHO) report emphasizes that 22 billion tonnes of water are used in tobacco production worldwide, 2 million tonnes of packaging waste are generated, and trees cut for tobacco production account for 5% of global deforestation, highlighting the environmental burden.[1] The environmental impacts of conventional cigarettes have been revealed by numerous studies.[2,3] Over the last fifteen years, the growing popularity

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of electronic cigarettes (e-cigarettes), including the production of disposable e-cigarettes, has raised questions about whether e-cigarettes are more environmentally friendly than traditional cigarettes.[4–6]

In 2021, it was estimated that there were 82 million e-cigarette users worldwide.[6] Data from the U.S. National Youth Tobacco Survey indicated that disposable e-cigarettes may represent a new public health issue.[5] In January 2020, the Food and Drug Administration prioritized enforcement against certain unauthorized flavored cartridge-based e-cigarettes. By July 2020, the FDA had issued warnings to seven companies to stop selling or distributing flavored disposable e-cigarettes and electronic liquids (e-liquids).[7] E-cigarettes, particularly those containing disposable devices, e-liquid, containers, packaging, and batteries, have been identified as a potential new global public health concern.[4] Additionally, attention has been drawn to the environmental impacts of e-cigarette use.[8,9] Some studies suggest that disposable e-cigarettes should be classified as hazardous waste. Despite their small size, disposable e-cigarettes are consumed and discarded much faster than reusable e-cigarettes. The use of reusable e-cigarettes also generates significant waste, including wires, cartridges, batteries, plastic components. This situation may necessitate specific measures for waste management. Even the disposal of unused and expired e-cigarettes and e-liquids by manufacturers may require hazardous waste management.[10] It has also been suggested that guidelines should regulate the environmental disposal of e-cigarette components.[11] Scientific studies investigating the environmental impacts of e-cigarette production, use, and disposal are quite limited. Despite the lack of information on the environmental effects of e-cigarettes, it is noteworthy that some e-cigarettes are marketed as "environmentally friendly" or "green" by manufacturers.[12]

This review aims to reveal the environmental impacts of e-cigarettes, which have significantly increased in use over the last 15 years and are expected to become a major public health problem in the future, and to evaluate these impacts within the framework of the United Nations Sustainable Development Goals (SDGs). A descriptive case study, a qualitative research design, was used for this purpose.

E-Cigarette Use

In addition to the continuous rise in e-cigarette usage rates, it is also important to understand how much users consume per day to obtain comparable data with traditional cigarettes and estimate the level of waste that may result. In this context, intensive, repeated measurement data collected in real time is critical to assess e-cigarette usage patterns.[13] According to the European Commission's latest public opinion survey on Europeans' attitudes towards tobacco, 72% of e-cigarette users reported using a refillable device, 23% reported using a reusable device that can be recharged with a disposable cartridge (POD system), and 8% reported using a disposable device that is discarded after use.[14] In the 2023 report of the National Youth Tobacco Survey, conducted annually in the United States, 10% of high school students (1.56 million) and 4.6% of middle school students (550,000) reported using e-cigarettes. Among current e-cigarette users, disposable e-cigarettes were the most commonly used device (60.7%), followed by pre-filled or refillable pods or cartridges (16.1%).[15] In another study, it was revealed that e-cigarette users change their coils on average three times per month.[16] Additionally, in a study measuring the e-liquid consumption of 91 participants from Maryland between April 2019 and March 2020, e-cigarette reported using an average of 3 mL of e-liquid per day, with a nicotine concentration of 18 mg/mL.[17]

Environmental Burden of E-Cigarettes

One of the emerging environmental problems caused by tobacco products, with the potential to become a much larger issue in the future, is the electronic waste (e-waste) generated by e-cigarettes and similar products. E-waste is the fastest-growing hazardous waste stream globally. By 2019, global e-waste reached 53.2 million tonnes (Mt), and it is projected to rise to 74.7 Mt by 2030.[18,19] The increasing use of e-cigarettes in developed and emerging markets leads to the disposal of e-cigarette waste in landfills, contributing to the release of chemical pollutants and rapidly altering the composition of e-waste. It was estimated that approximately 50 million tonnes of e-cigarettes were wasted globally in 2017.[9,20] The waste generated by e-cigarette cartridges and batteries is a serious concern. Improper disposal of these materials in the environment poses significant dangers.[21,22]

Efforts to reduce cigarette butt litter have been the primary focus of studies on tobacco product waste.[2,3,23] However, much of the research on e-cigarettes has concentrated on their health effects, intended use, and health hazards.[24,25] There remains a notable gap in research concerning awareness of e-cigarette waste and environmentally friendly disposal practices.[26]

When evaluating the environmental impacts of e-cigarettes, key environmental concerns include greenhouse gas emissions from e-cigarette production, exposure to chemicals in the e-cigarette liquid and aerosol, improper disposal of e-liquids or cartridges (with or without nicotine), disposal of e-cigarettes containing batteries, and the plastic packaging of the cartridges. More data is needed to fully understand the environmental impacts of manufacturing these products, particularly due to the lack of regulatory consistency in product availability and production reporting.[12] There is an urgent public health concern regarding the environmental effects of e-cigarettes, from production to disposal, which requires immediate investigation.[27]

Ngambo and colleagues (2023) analyzed the environmental impacts and found that the production, use, and disposal of e-cigarettes pose threats to air quality, water, land use, and animals.[28] Furthermore, no formal assessment of the life-cycle environmental impacts of e-cigarettes has been found,[9,19] highlighting the need to clarify how e-cigarettes compare to traditional cigarettes in their environmental effects.[12]

Leaching tests of e-cigarette components have shown that the lead content in the resulting leachate is up to 10 times higher than the U.S. legal limit for hazardous waste.[10] E-cigarette filters, mouthpieces, rubber plugs, and cartridge plastics have also been found to contain other toxic or potentially toxic compounds.[29] Another study, which used Lemna minor as a model organism to study the effects of tobacco, e-cigarettes, and e-liquids, found that exposure to e-cigarettes and e-liquids caused a reduction in root length, biomass, and leaf number compared to controls. The presence of cigarette butts, e-cigarettes, or e-liquids caused stress in the model plant, which may indicate degradation of aquatic ecosystems at the primary producer level due to significant deviations from control conditions.[30] The literature reports that lead is the only element in e-cigarette products that exceeds hazardous waste levels, with lead leaching occurring at dangerous levels. Another hazardous substance in e-cigarette products is nicotine, present in e-liquids.[10]

Substances in e-cigarettes can contaminate soil, water, and air.[9] Copper and nanoparticles have also been detected in e-cigarette aerosols. Copper levels were 6.1 times higher than the per-breath value reported for traditional cigarette smoke. The detection of copper, a potentially cytotoxic metal, as well as oxidants in e-cigarettes and their components, raises concerns about the safety of e-cigarette use and the disposal of e-cigarette waste products into the environment.[11] According to the U.S. Environmental Protection Agency (EPA) Toxicity Characteristic filtration protocol, 51 e-cigarettes were analyzed, and barium, chromium, nickel, and lead were detected. The study showed that the acceptable lead level in disposable e-cigarettes was exceeded. In a separate study investigating metal leaching in 23 disposable e-cigarettes in the U.S., high levels of lead were detected in the leachate of some devices. Specifically, two out of the 15 e-cigarettes tested exceeded legal threshold levels for lead.[10]

Heating coils used for aerosol production are typically made of metal alloys across all generations of e-cigarettes. Common coil materials include kanthal, nichrome, and stainless steel.[31] E-liquids contain nicotine and other chemicals that can harm human health.[32,33] In 2015, more than 58 million e-cigarettes and spare parts were sold in grocery and convenience stores in the U.S. (excluding e-cigarette stores or online sales), with 19.2 million of these products designed for single use. Also, in 2015, 99% of e-cigarette products sold contained nicotine. Specifically, 98.7% of flavored e-cigarette products and 99.4% of unflavoured products contained nicotine.[34,35] The disposal of e-cigarettes is further complicated by the presence of significant amounts of residual nicotine, making e-cigarettes and cartridges both e-waste and biohazardous waste.[10]

Kari (2019) predicted that e-cigarette waste could become a major waste management disaster if not handled responsibly.[36] Toxicology reports have also shown that e-cigarette leaks have adverse effects on aquatic animals when ingested.[20,37] The impact of cigarette butts, heat-not-burn tobacco products, e-cigarette cartridges, and e-liquids on microorganisms was investigated using microbial analysis in the risk assessment (MARA) method. The MARA method assesses ecotoxicity by using 11 different microorganisms, which can provide informa-

tion on chronic ecotoxicity. The results revealed that e-cigarette waste, such as cartridges and e-liquids, do not pose a significant threat to microbiocenosis. On the other hand, leachate from cigarette butts and butts from heat-not-burn tobacco products has been reported to have a significant ecotoxic effect on the microorganisms studied. It was found that even a few dozen conventional cigarette butts in water could inhibit microbial growth, and heat-not-burn tobacco products exhibited high toxicity toward D. acidovorans and S. warnerii.[38]

The introduction of plastic, metal, cartridges, lithium-ion batteries, and concentrated nicotine solutions requires far more environmentally intensive production processes than products made primarily from plant material and plastic filters, such as combustible cigarettes.[39] Furthermore, the majority of e-cigarettes currently in use are neither reusable nor recyclable.[27]

Even the few refillable tank systems sold still use plastics, metals, batteries, and other non-biodegradable materials that ultimately become e-waste in landfills. If we assume that most smokers' lax environmental habits carry over to e-cigarette users, it is likely that these products will also end up as e-waste, polluting beaches, seas, cities, and the countryside.[40] The WHO has stated that single-use, hard plastic cartridges for e-cigarettes could become the cigarette butts of the future.[41]

These components include metal housings, wires, plastics, and absorbent polymers that hold parts together and retain vaporized liquids. Many of these parts may become contaminated with toxic substances found in e-cigarettes.[39,42] In this context, environmental precautions must be taken in case of contamination by the substances found in e-cigarettes, and the data on environmental hazards are summarized in Table 1.

The table presents environmental precautions and hazards that should be addressed in case of contamination by the substances found in e-cigarettes, using data from the Material Safety Data Sheet (MSDS). Additionally, the environmental characteristics of these substances are specified, and EPA waste codes are provided for each agent. The United States Environmental Protection Agency has concluded that e-cigarettes can be classified as acutely hazardous waste (P075) when disposed of, due to the cartridges containing commercial chemical products, especially nicotine.[65] Analysis of the table reveals that certain ecotoxic compounds, such as lead and arsenic found in LED lamps, can also be present when e-cigarettes are discharged into the environment as e-waste. Lead is particularly concerning because of its chronic toxic effects on aquatic microorganisms. Another hazardous compound in e-cigarette disposal is mercury, which is used in thermometers to measure e-cigarette temperatures and is also harmful to aquatic ecosystems. Heavy metals such as lead, arsenic, and mercury, which may contaminate e-cigarette waste, pose risks to human health through biomagnification and can have toxic effects, especially on the central nervous system.[66] Circuit board e-waste from e-cigarettes can contaminate the environment with various metals, including lead, copper, zinc, aluminum, nickel, arsenic, barium, cadmium, and selenium.[67]

Research focusing on disposal patterns and environmental impacts shows that cigarette pollution, e-waste, and e-cigarette disposal are emerging public health concerns.[68] The U.S. Food and Drug Administration (FDA) has stated that regulation will require e-cigarettes to undergo extensive testing if they are to remain on the market. However, e-cigarette manufacturers are able to produce and sell their devices with minimal oversight from health and environmental regulators, as the deadline for this requirement has been delayed from 2018 to 2022.[69]

Conclusion

Despite growing concerns about the environmental threat posed by e-cigarettes, more scientific studies are needed to fully understand the environmental impact of their life cycle—production, use, and disposal. The effects of this life cycle on human health, particularly regarding environmental pollution, need to be thoroughly analyzed. Although limited data on the life cycle of e-cigarettes have been reported, it is evident that they may pose a significant long-term environmental threat due to the toxic nature of their components.[27,28] E-cigarette production can increase pollution, including greenhouse gas emissions, which may contribute to climate change.[12] In this context, many studies emphasize the same point: given the rapid expansion of e-cigarette production, distribution, use, and disposal worldwide, a rigorous assessment of their life-cycle environmental burden—considering various potential health, environmental, and other consequences—is urgently needed.[28]

Table 1: Environmental precautions and hazards for e-cigarette ingredient contamination

Agent	Environmental precautions	Environmental hazards agency (EPA) waste code	Environmental protection
Nicotine[43]	Keep away from drains, surface water, and groundwater.	Hazardous to the aquatic environment.	P075
Propylene Glycol[44]	Prevent from entering soil, ditches, sewers, waterways, and/or groundwater.	Not considered environmentally hazardous based on available data.	P075
Polyethylene Glycol 400[45]	Keep away from drains, surface water, and groundwater. dangerous goods regulations.	Not environmentally hazardous according to	–
Vegetable Glycerine[46]	In the event of a leak, remove all sources of ignition and stop the leak if possible. Protect against the product entering watercourses.	Avoid discharge of spilled material into the environment or waterways.	–
Lithium-Ion Batteries[47]	Bind released ingredients with powder (e.g., rock salt, sand). Dispose of according to local laws. Avoid substances penetrating the earth, sewers, or water.	–	D001 D003
Lithium[48]	Keep away from drains, surface water, and groundwater.	Not environmentally hazardous according to dangerous goods regulations.	–
Light (Lamps)[49]			
Arsenic[50]	Keep away from drains, surface water, and groundwater. The product is an acid. Neutralize the product before discharging into sewage systems.	Very toxic to aquatic life with long-lasting effects.	D004
Copper[51]	Keep away from drains, surface water, and groundwater. Retain contaminated washing water and dispose of it. Inform authorities if substance enters watercourses or sewers.	Hazardous to the aquatic environment.	–
Nickel[52]	Avoid discharge into drains, watercourses, or onto the ground. Avoid discharge into the aquatic environment.	No specific hazard identified.	–
Lead[53]	Avoid release into the environment.	Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.	D008
Iron[54]	Keep away from drains, surface water, and groundwater. dangerous goods regulations.	Not environmentally hazardous according to	–
Silver[55]	Keep away from drains, surface water, and groundwater.	Not environmentally hazardous according to dangerous goods regulations.	D011
Measure temperature (Thermometers)			
Mercury[56]	Keep away from drains, surface water, and groundwater. Retain contaminated washing water and dispose of it properly.	Hazardous to the aquatic environment.	D009
Circuit Boards (Lead, Copper, Zinc, Aluminum, Nickel, Arsenic, Barium, Cadmium, Selenium)			
Cadmium[57]	Prevent from entering drains, sewers, or waterways; do not release into the environment.	Hazardous to the aquatic environment.	D006
Selenium[58]	Keep away from drains, surface water, and groundwater. Retain contaminated washing water and dispose of it properly.	Not environmentally hazardous according to dangerous goods regulations.	D010
Barium[59]	Prevent from entering drains, sewers, or waterways; do not release into the environment.	–	D005
Zinc[60]	Keep away from drains, surface water, and groundwater.	Not environmentally hazardous according to dangerous goods regulations.	–

Table 1: Cont.

Agent	Environmental precautions	Environmental hazards agency (EPA) waste code	Environmental protection
Microprocessor	–	Keep away from drains, surface water, and groundwater.	–
Wire			
Chromium[61]	Keep away from drains, surface water, and groundwater.	Not environmentally hazardous according to dangerous goods regulations.	D007
Aluminum[62]	Keep away from drains, surface water, and groundwater.	Not environmentally hazardous according to dangerous goods regulations.	F019
Iron[54]	Keep away from drains, surface water, and groundwater.	Not environmentally hazardous according to dangerous goods regulations.	–
Nickel[52]	Avoid discharge into drains, watercourses, or onto the ground. Avoid discharge into the aquatic environment.	No specific hazard identified.	–
Protective container			
Iron[54]	Keep spilled material away from heat, sparks, and open flames.	–	–
PVC[63]	Ensure adequate ventilation.	–	–
Chlorinated polyethylene[64]	Prevent from entering the sewer system, surface water, or soil.	–	–

Source: The authors created the table using Material Safety Data Sheet data

Given the steady increase in the number of e-cigarette consumers, this potential problem is of particular concern,[70] and the importance of this research is heightened, especially with the focus on young people. A study conducted in high schools in the USA showed that e-cigarette products accounted for 19% of cigarette litter in the outdoor environment and ranked second only to traditional cigarettes.[71] As we can see, the environmental burden has begun to manifest, but the process of implementing necessary measures is progressing slowly. E-liquids and e-cigarette waste are subject to hazardous waste regulations.[65] The material composition of e-cigarettes is more akin to that of a smartphone than a traditional cigarette. In the current e-cigarette market, some brands remain silent regarding the disposal of their products. Although some companies are working on recycling e-waste as part of their producer responsibility, the process remains difficult for consumers. One initiative taken by companies includes a disposal plan called "green cigarettes." In this waste disposal plan, consumers were asked to mail in 80 e-liquids of any type or brand in exchange for reward points. Another plan involves the e-cigarette company establishing recycling points where e-cigarette batteries are collected. While this practice is primarily concentrated in large metropolitan areas, it is essential for effective waste disposal.[27]

Article 18 of the WHO Framework Convention on Tobacco Control (FCTC) addresses the environmental hazards of tobacco. The article states that the parties "agree to pay due regard to the protection of the environment about the cultivation and manufacture of tobacco in their territories, and to human health about the environment."[72] In addition, various policies have been proposed to ensure that the tobacco industry is held accountable for the environmental damage caused by its products. The WHO has stated that the MPOWER policy package (Monitor tobacco use, Protect people from tobacco smoke, Offer help to quit, Warn about the dangers of tobacco, Enforce bans on advertising, and Raise taxes), which supports the implementation of FCTC policies, can be utilized to reduce the environmental damage caused by tobacco.[73] It is recommended that this approach be extended to include e-cigarettes and that countries where e-cigarettes are sold should take action. In this context, several measures can be taken, particularly in countries where the sale and use of e-cigarettes are prohibited. These measures include the following:

- Collection of data on e-cigarette use,
- Preparation of disposal procedures and guidelines for e-cigarette waste and development of international cooperation,
- Prioritizing environmental sustainability in the disposal of e-cigarette waste,
- Supporting research on the environmental impacts of e-cigarettes and waste disposal and allocating funds for research,
- Ensuring the establishment of e-cigarette waste management units and developing programs with local governments,
- Strict supervision of e-cigarette manufacturers and the introduction of stringent product regulations,
- Establishing standards for the design of e-cigarettes to facilitate easier recycling and proper disposal by manufacturing companies,
- Developing programs for manufacturers to buy back used products while selling new ones,
- Involving companies in the disposal process and introducing significant obligations,
- Providing training on the environmental impacts of e-cigarettes and incorporating this topic into school curricula.

Sustainable development is defined as "development that meets the needs of present generations while not jeopardizing the ability of future generations to meet their needs."[74] The SDGs demonstrate that health cannot be considered in isolation from other factors, including the environment. Within the SDGs targeted for 2030, based on the principles of sustainable development, it is crucial to accelerate the creation of policies for the disposal of e-cigarette waste. E-cigarette waste occupies a significant place among e-waste, directly impacting the goals of good health and well-being, clean water and sanitation, climate action, life below water, and life on land. It is viewed as a growing problem for the future. By 2030, countries striving to achieve the SDGs should incorporate the environmental damage caused by tobacco into their strategies for achieving these goals and adopt regulations that mandate extended producer responsibility, including for e-cigarettes.[68]

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Concept – İ.H.C., G.G.; Design – İ.H.C., G.G.; Supervision – İ.H.C.; Data collection &/or processing – İ.H.C., G.G.; Analysis and/or interpretation – İ.H.C., G.G.; Literature search – İ.H.C., G.G.; Writing – İ.H.C., G.G.; Critical review – İ.H.C., G.G.

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