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Systematic Review

The Environmental Impact of E-Waste Microplastics: A Systematic Review and Analysis Based on the Driver–Pressure–State–Impact–Response (DPSIR) Framework

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Abstract: Microplastics resulting from the fragmentation of plastics in electronic waste (e-waste) are an emerging but understudied environmental concern. This systematic review employs a Driver–Pressure–State–Impact–Response (DPSIR) framework to investigate the sources, prevalence, and environmental effects of e-waste microplastics, identifying knowledge gaps. The available literature on e-waste microplastics was retrieved from Scopus and Web of Science (n = 24), and trends in electrical and electronic equipment were retrieved from European Union databases. The growing incorporation of electronics into daily life results in a global annual growth rate of 3–4% for e-waste, of which only 17.4% is collected for recycling. E-waste microplastics are frequently found in soils near disposal or disassembly facilities, potentially leaching hazardous metals (e.g., Pb) or organic compounds (e.g., flame retardants). These microplastics contaminate the food chain and can have adverse effects on the soil and gut microbiome, organisms, and human health, either independently or associated with other chemicals. Responses include the implementation of regulations, improvement of waste management systems, and mitigation measures. Despite these concerns, the literature on the topic remains limited, emphasizing the need for additional research on the identification of e-waste microplastics and their toxicity.

Keywords: e-waste; electronic waste; waste electrical and electronic equipment (WEEE); microplastics; driver–pressure–state–impact–response framework

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1. Introduction

Electrical and electronic equipment (EEE) is one of the fastest-growing waste streams (e-waste) [1]. E-waste is composed of 30% organics (e.g., plastics, additives), 30% ceramics (e.g., silica), and 40% inorganics (i.e., metals) [2]. While waste electrical and electronic equipment (WEEE) contains a large fraction of plastics, these are difficult to identify and separate and may be contaminated with additives and metals, making them harmful and compromising their recyclability [3]. EEE plastics generally contain brominated flame retardants, often used in co-association with the flame-quenching synergist Sb_2O_3, leading to the frequent use of Br and Sb in their identification [4]. The release of flame retardants and other hazardous materials, such as metals, raises concerns over the mismanagement of e-waste [5]. In addition to the environmental consequences of landfilling or illegal dumping and wasting precious resources, e-waste is often collected and recycled by informal workers without safety precautions [6]. The problem is aggravated by exporting WEEE to developing countries [1].

When mismanaged, plastics in e-waste may degrade and fragment into microplastics enriched with metals and organic compounds. These e-waste microplastics can more easily move across environmental compartments and interact with organisms, leading to adverse effects. Compared to larger plastic objects, microplastics are more likely to cause adverse effects due to being more likely to be ingested by organisms and their higher surface area, which facilitates leaching and promotes interaction with other compounds [7]. Moreover, successive fragmentation of plastics originates an exponentially higher number of particles of increasingly smaller sizes, further increasing the possibility of environmental dispersion and translocation of microplastics to tissues [8]. Thus, the objective of this work is to review the existing literature on e-waste microplastics, to build a Driver–Pressure–State–Impact–Response (DPSIR) framework, and to identify knowledge gaps. Although there is a voluminous body of literature on e-waste [9–11], this work is innovative in that it solely addresses e-waste microplastics due to the expected differences in behavior compared to larger objects, summarizing the information gathered by a systematic literature review on an actionable DPSIR framework.

The DPSIR framework has been supported by the European Environmental Agency (EEA) and the Organization for Economic Co-operation and Development (OECD) [12,13]. It has been used to illustrate relationships between society and the environment in a simple and neutral way. Indicators categories include (i) drivers, namely socioeconomic trends that induce changes in production and consumption; (ii) pressures, including the release of substances, resource use, or land use; (iii) state, which describes the biotic and abiotic conditions of the environment; (iv) impact, the adverse effects on the environment; and (v) responses, including mitigation and corrective measures. The following sections have been organized based on these categories of the DPSIR framework, providing the background to reach a final concept.

2. Materials and Methods

Literature research was conducted following PRISMA guidelines (Figure 1). While e-waste lacks a consensual definition due to the diversity of products [14], this review will follow the scope defined in European Directive 2011/65/EU [15]. Literature was retrieved from SCOPUS and Web of Science by searching for "((“e-waste” or “electronic waste” or “waste electrical and electronic equipment”) and “microplastics”)” in November 2023. A total of 63 documents were retrieved, of which 20 were duplicates. All article types besides original research articles were excluded from the analysis. Commentaries, editorials, and reviews comprised the largest part of the excluded documents ($n = 10$), but none addressed e-waste microplastics. These works addressed emerging contaminants in different countries or regions (Nigeria, Middle East, North Africa) [16–18], plastic additives (bisphenol A, decabromodiphenyl ethane) [19,20], plastic waste management [21], human health impacts [22,23], ecotoxicity in phytoplankton [24], and the use of hemocytes to study the toxicity of microplastics and other contaminants [25]. Four books, all addressing waste technologies, were identified and excluded. Finally, articles out of the scope of this work (i.e., not addressing e-waste microplastics) were excluded ($n = 5$), namely, microplastics from glass recycling [26], found in marine fish species [27], contributing to antibiotic resistance in sludge [28], on international agreements [29], and on 3D printer waste (as it addressed microplastics generated in the activity and not those directly from electronics) [30]. A total of 24 research articles were reviewed, comprising all available original literature at the time. In addition, grey literature from the European Union (EU) was accessed to gather information on consumption and waste production. The novelty of this work consisted of being a systematic review focusing on microplastics and describing e-waste production as driving forces, resulting in a DPSIR framework.

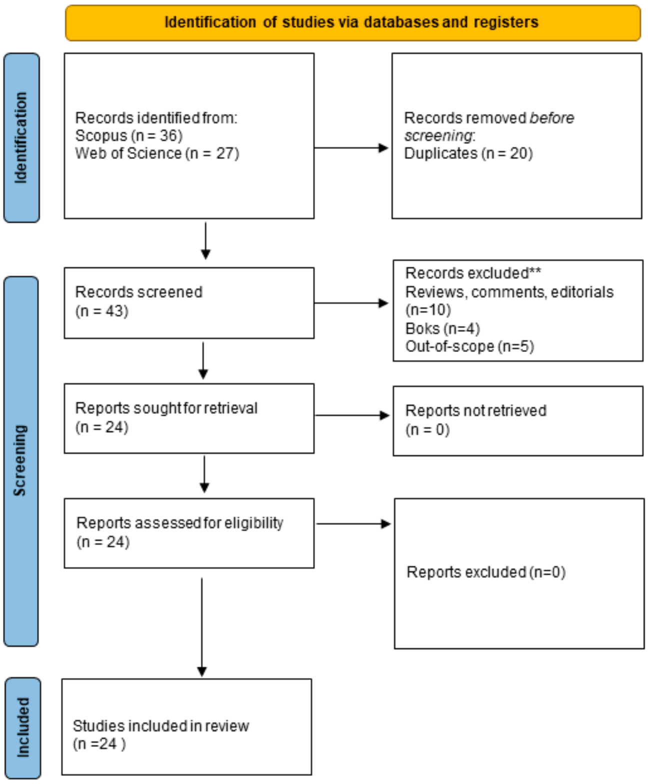

Figure 1. PRISMA guidelines flow-chart for the selection of works addressing e-waste microplastics in November 2023.

3. Results and Discussion

3.1. Drivers and Pressures: Trends in Electronics Consumption and E-Waste Production in the European Union

In the EU, electrical and electronics (6.2%) is the fourth biggest end-use market for plastics, after packaging (40.5%), building and construction (20.4%), and automotive (8.8%), being mainly comprised by polypropylene and other thermoplastics [31]. In 2018, 23.02 and 8.94 kg hab^{-1} of electrical and electronic equipment were put on the market or collected as waste in the EU, respectively [32]. In the same year, the main categories by weight entering the market were large household appliances (4.4 Mt), consumer equipment and photovoltaic panels (1.0 Mt), and IT and telecommunications (0.9 Mt) [32]. It is worth considering that many of these are long-term applications (e.g., photovoltaic panels have an estimated lifespan of 25 years). Moreover, IT and telecommunication are noteworthy for the reduced individual weight of these gadgets compared to the other two categories. Although there is a trend for increasing the weight of products put on the market, the tendency is less clear at the category level (Figure 2). In the United States, stagnation or decline in household e-waste was attributed to the increasing use of lightweight technologies [5].

A global increase in WEEE is expected due to the permeation of electronics in daily life, following an annual growth rate of 3–4% [1]. In 2019, e-waste was mainly produced in Asia (24.9 Mt, 5.6 kg hab^{-1}), the Americas (13.1 Mt, 13.3 kg hab^{-1}), and Europe (12 Mt, 16.2 kg hab^{-1}), but very little was collected, corresponding to 11.7%, 9.4%, and 42.5%, respectively [2]. Despite being one of the top producers of e-waste, Europe is the continent with the highest collection rate. Yet, only 17.4% of e-waste is collected at a global level [2], raising concerns over the remainder. Up to 80% of WEEE collected in the EU is recycled, but less than half is properly collected [33]. In China, the production of recycled plastics from WEEE has shown an annual growth rate of 11.8%, mostly for acrylonitrile butadiene styrene, polypropylene, and polystyrene [34]. Mismanaged WEEE can release microplastics, metals, and organic compounds with consequences to environmental, animal, and human health.

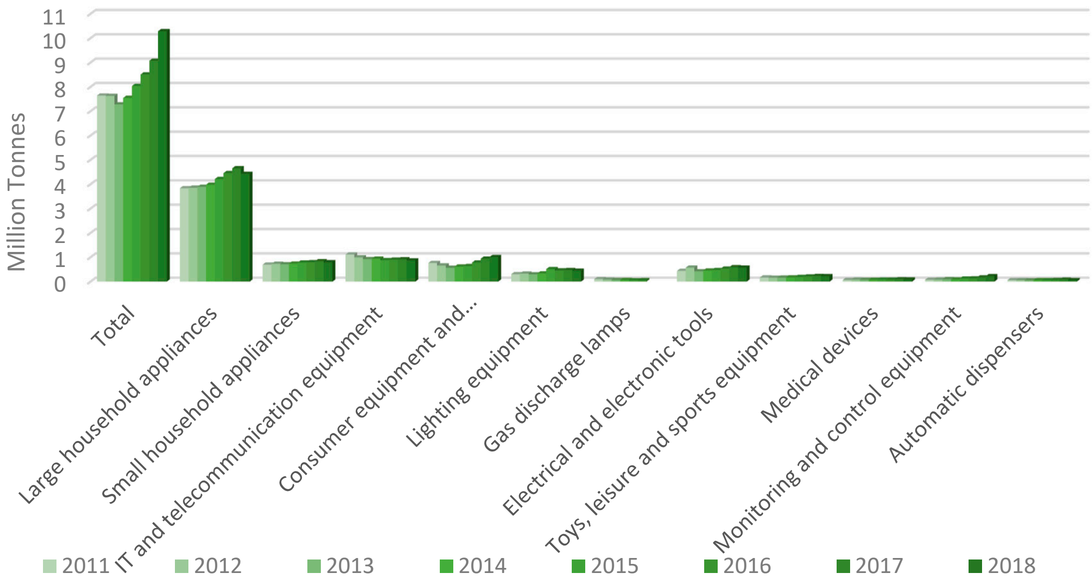

Figure 2. Waste electrical and electronic equipment (WEEE) put on the market in the European Union by category. Adapted from [32].

3.2. State: Concentrations of E-Waste Microplastics in the Environment

Microplastics have been found in soils near e-waste disassembly, recycling, or dumping sites in 10^3–10^5 particles kg^{-1} concentrations (Table 1). Comparatively, the overall concentration of microplastics in soils has been estimated as 4482–12,686 particles kg^{-1} (95% confidence interval) [35]. Disposal and recycling facilities for e-waste can be considered sources of e-waste microplastics where higher concentrations have been found (Figure S1). Microplastics can then migrate deeper into the soil [36] or to the surrounding environment [37]. A total annual emission of 40.5 g of microplastics was estimated in an e-waste dismantling plant in China [37]. Common plastic e-waste includes wiring insulation and casings from small electronics [4,38], which can then be found in the environment as black particles or fragments.

E-waste microplastics were also found in fluvial beach sediments in Brazil as blue fibers presenting Cu_2FeSnS_4 (240.7 particles m^{-2}, comprising 40% of microplastics sampled) [39] or originating from beached ink cartridges lost at sea [40]. Moreover, wastewater treatment plants may release bio-beads produced from recycled WEEE [41] or microplastics originating from wearable electronic textiles [42]. Global concentrations, sources, and pathways of e-waste microplastics in the environment are currently unknown since most sampling studies cannot differentiate them.

Table 1. Concentrations of e-waste microplastics in terrestrial environments.

Sample	Location		Concentration		Type		Reference
	Region	Facility	Mean	Maximum	Polymers	Shapes	
Soil	Guiyu, China	E-waste disassembling site (abandoned)	9450 particles kg^{-1}	34,100 particles kg^{-1}	PS (12.44%), PP (11.98%), PVA (10.51%), polyphenylene sulfide (7.74%), PE (5.35%)	granules (96.42%), <1 mm (88.61%), black (33.17%), white (33.17%)	Chai et al., 2020a; Chai et al., 2020b; Chai et al., 2021 [43–45]
	Longtang County, China	E-waste recycling site	2250 particles kg^{-1} (12.2 mg g^{-1}),	14,200 particles kg^{-1} (153 mg g^{-1})	ABS	blue, black, red	Zhang et al., 2021 [46]
	Shanghai, China	E-waste disassembling site	24,888 particles kg^{-1}	130,680 particles kg^{-1}	PMMA, other 102 kinds	white, black	Zhan et al., 2022 [47]
	India	E-waste dumping sites	1411 particles kg^{-1}	13,245 particles kg^{-1}	PET, PVC	na	Tun et al., 2022 [38]

Table 1. *Cont.*

Sample	Location		Concentration		Type		Reference
	Region	Facility	Mean	Maximum	Polymers	Shapes	
Dust	China	Roads inside an e-waste disassembling site	na	7778 particles 5 g^{-1}	tire rubber, PS, PP, PMMA	na	Zhang et al., 2022 [37]
	Shanghai, China	E-waste disassembling site	44,277 particles 50 g^{-1}	261,970 particles 50 g^{-1}	na	na	Zhan et al., 2022 [47]
Air	Shanghai, China	E-waste disassembling site	530 particles 100 m^{-3}	1102 particles 100 m^{-3}	na	na	Zhan et al., 2022 [47]

ABS: acrylonitrile butadiene styrene; PE: polyethylene; PET: polyethylene terephthalate; PMMA: polymethyl methacrylate; PP: polypropylene; PS. polystyrene; PVA: polyvinyl alcohol; PVC: polyvinyl chloride; na: not available.

3.3. State: Additives and Leachates from E-Waste Microplastics

E-waste microplastics are enriched in metals (e.g., Pb) and organic compounds (e.g., flame retardants), stemming from plastic additives or contact with metals in electronics. For instance, metal recovery from WEEE produces a non-metallic fraction (NMF) containing 1 mm fragments of plastics (i.e., microplastics), fiberglass, and unseparated metal. The black and wrinkled bio-beads produced from recycled WEEE used in wastewater treatment plants are also enriched in metals (e.g., Br, Cd, Cr, Pb) and have been found in English beaches [4,41]. Compared to soils, e-waste microplastics presented higher concentrations of seven metals (Pb, Cd, Cr, As, Ba, Co, Ni) in Guiyu, China [43], and higher concentrations of halogenated flame retardants (HFRs) [46] and similar concentrations of organophosphate flame retardant in Longtang County, China [48]. Microplastics collected from marine beaches on the southern coast of Sri Lanka also presented high concentrations of brominated polycyclic aromatic hydrocarbons (PAHs), suggesting that they might have originated from mismanaged e-waste [49]. Since brominated flame retardants and synergists (e.g., Sb_2O_3) are often used in EEE, the identification of e-waste microplastics in the environment could be based on the high concentrations of Br and Sb (e.g., Br > 5%) [4,50]. However, this criterion may be limited by an increase in recycled plastics incorporating WEEE, which contain additive residues [50]. The identification of e-waste microplastics would add an additional layer of complexity to analytics, entailing the use of techniques such as X-ray fluorescence spectrometry for the detection of trace elements or pyrolysis gas chromatography–mass spectrometry to detect associated organic compounds.

Soils near e-waste facilities may be contaminated with metals, such as Cu and Pb, and organic compounds, including PAHs, bisphenol A, phthalic acid esters, and bis (2-ethylhexyl) adipate [51]. Likewise, concentrations of plasticizers and bisphenol A were four times higher in surface river sediments near e-waste recycling sites than in other areas (residential/commercial, industrial) [52]. However, it is not clear if metals and organic contaminants found in the environment surrounding disposal or recycling facilities originate from microplastics' leachates or from the direct release of contaminants originating from volatile losses, runoff, wastewater, or combustion.

Leaching from microplastics depends on the specific substance and environmental conditions (e.g., the presence of organic matter or cations) [36,41]. For instance, acid rain can lead to the migration of NMF deeper into the soil and the leaching of Br, Pb, Zn, and Cu [36]. Other studies suggest that leaching from plastics plays a small role in the contamination of soils near disassembling facilities (e.g., <10% for halogenated flame retardants) [46], being released independently and simultaneously from a common source [47]. Laboratory tests also support the weakly adsorption of decabromodiphenyl ether (i.e., brominated flame retardant) in an aqueous solution to microplastics compared to soil [53]. However, results were influenced by the size of microplastics, with increased leaching from particles < 2 mm [53]. Finally, a study on the e-waste–water partition coefficient reveals that the percentage leached varies greatly even within additive categories, demonstrating this variation for bisphenol (0.1–83.0%) and benzophenones (0.4–62.0%) [54]. A study of

WEEE treatment emissions shows that an average of 27% of organic compounds were distributed in the ultrafine fraction of particulate matter, which may include microplastics [55]. Therefore, a conclusion cannot be reached regarding the contribution of leachates since it will depend on microplastics' characteristics, environmental conditions, and the properties of each individual additive or metal. Moreover, microplastics could also adsorb contaminants from soil in an inverse direction. Future studies should investigate the relative contribution of microplastics' leachates under conditions found near disposal or recycling facilities and how the loss of these contaminants might compromise the identification of e-waste microplastics based on Br and Sb.

3.4. Impacts: Adverse Effects of E-Waste Microplastics and Leachates on the Environment and Ecosystems

E-waste microplastics and associated contaminants can already be found in environmentally exposed organisms. In China, microplastics were found in food webs surrounding an e-waste facility, namely in aquatic invertebrates (22.6–57.8 particles per individual), terrestrial invertebrates (37.1–182.0 particles per individual), fishes (38.1–130.0 particles per individual), snakes (132 particles per individual), birds (150–1250 particles per individual), and voles (171 particles per individual) [56]. Moreover, fish (*Anabas testudineus*) from e-waste-contaminated sites in Guiyu, China, presented liver concentrations of Ag, Cd, and Pb that were 40.73, 27.07, and 6.01 times higher than reference sites, respectively [57]. It is not clear if exposure to metals occurred directly or through the release of microplastics' leachates in the digestive system. Exposure of WEEE-derived bio-beads to a simulated avian digestive solution reveals high mobility for Fe and Zn, reaching a maximum of 1120 and 161 $\mu g\ g^{-1}$, respectively, but with low availability of Br, Cd, Cr, Pb, and Sd [41]. Thus, the release of leachates from e-waste microplastics under digestive system conditions cannot be excluded but also requires further investigation.

E-waste microplastics seem to be more toxic than other plastic types [58], possibly due to the increased content of metals and plastic additives. The degradation of e-waste plastics could also produce new xenobiotics or mobilize existing compounds. Electronic waste and keyboard plastic leachates caused growth inhibition and decreased photosynthetic capacity in the microalgae *Scenedesmus vacuolatus*, with higher effects after degradation under the UV light, and produced more adverse effects than regular consumer plastics (i.e., polyethylene, polyethylene terephthalate, polypropylene, and polystyrene) [58]. In earthworms (*Eisenia fetida*), co-exposure to decabromodiphenyl ethane (DBDPE, i.e., brominated flame retardant) and microplastics (i.e., polypropylene, polyethylene, and polylactic acid) resulted in toxicity to the nervous systems, epidermis, and gene regulation [59]. Moreover, earthworm co-exposure to DBDPE to microplastics (acrylonitrile butadiene styrene) increased bioaccumulation (of the additive), damaged the epidermal barrier, and had detrimental effects on signal pathways and on the regulation of lysosomes, phagosomes, and apoptosis [60].

E-waste microplastics are colonized by specific bacteria [44] and can change species diversity in soil [36]. For instance, the family *Hyphomonadacea* found on the surface of e-waste microplastics in the soil may play a role in hydrocarbon degradation [44]. Microplastics are known to change soil properties, including water evaporation, bulk density, and microbial activity [61,62]. Moreover, the release of metals and organic compounds could also originate changes in soil or gut microbiome, possibly due to the presence in the environment of metal-transforming bacteria (e.g., *Cetobacterium somerae*, *Clostridium colicanis*) and metabolic changes [57]. Therefore, besides toxicity, the modulation of microbiota by e-water microplastics and associated contaminants can also cause adverse effects on organisms and ecosystems. Laboratory assays could help clarify which factor leads to the modulation of microbial communities. Moreover, potential plastic-degrading microorganisms may be identified by studying species colonizing e-waste microplastics' surface (e.g., *Hyphomonadacea*, [44]).

Effects are also expected at the ecosystem level since estimated concentrations of e-waste microplastics near disassembling or recycling facilities (Table 1) exceed low effect concentration (LOEC) for microplastics in soils, estimated at 539–7175 particles kg^{-1} [35]. Moreover, risk quotients (RQ) showed high ecological risk (RQ > 1) for the organophosphate flame retardants triphenyl phosphate (RQ = 1490) and decabromodiphenyl ether 209 (RQ = 2.95) in soil [48]. Thus, even if associated contaminants and microplastics are released independently, they may present a synergistic toxic effect.

3.5. Impacts: Adverse Effects of E-Waste Microplastics on Human Health

E-waste microplastics or associated contaminants may be dangerous to human health (e.g., PAHs, [63]), directly or following accumulation in organisms for human consumption (e.g., wild fish, [57]). In a study of eight e-waste plastics from a recycling plant, direct exposure to plastics did not induce cytotoxic effects on multiple human cell lines in assays lasting 24 h, 96 h, and 168 h [64]. However, another study evaluating the risk of e-waste microplastics enriched with PAHs (43–236 $\mu g\ g^{-1}$ within 45 min) concluded that smaller microplastics adsorb higher concentrations and that leachates from particles could be hazardous to human health, presenting a carcinogenic risk [63]. Moreover, exposure to PAHs, volatile organic compounds (VOCs), and metals emitted by e-waste disassembling, especially during informal recycling activities, produced higher levels of oxidative stress in neighboring residents [6].

3.6. Response: Prevention and Mitigation of E-Waste Microplastics

Prevention and mitigation measures must be implemented at all stages to address e-waste microplastics. Measures should be applied to new EEE entering the market through more sustainable designs (e.g., higher recyclability or biodegradability [65]) by avoiding planned obsolescence and promoting the right to repair. The European Commission has already prepared a proposal for a directive on the rules of the right to repair [66], which may also contribute to a reduction in WEEE production. Valorization of e-waste plastics also requires improvements in recycling technologies [67], such as more efficient separation (e.g., through flotation with polymeric aluminum chloride) [68]. Critically, emerging technologies must address ways of removing contaminants, such as metals and additives, which may compromise recycled plastics' market value (e.g., restrict market applications).

Measures must also be implemented in waste management to reduce losses to the environment. Methods that have successfully reduced the population's exposure to contaminants released from e-waste sites include awareness campaigns, environmental protection policies, and improvement of waste management infrastructures [6]. For instance, systems used to prevent pellet loss may also be implemented in e-waste facilities, including proper packaging, cleaning spills, and having grates and fences to prevent losses [69]. All effluents from e-waste facilities must be properly treated to avoid the release of particles or associated contaminants. Mitigation measures might be applied to reduce the dispersal of microplastics in the environment (e.g., use of wetlands or physical barriers) and recover them by conducting frequent cleanup campaigns, using nets on treated water discharge pipes, or having other passive collection equipment (e.g., floating barriers, litter traps). Finally, local monitoring could help to audit the efficacy of current methods, identify improvement opportunities, and ensure environmental safety.

Implementation of any measures should account for a cost–benefit analysis, considering socioeconomic conditions and temporal and spatial scales [70]. A long-term approach includes improving waste management, while cleanups produce immediate results but may become costly when repeated over the years [70]. The cost of recycling e-waste has been estimated as 1–9 USD kg^{-1}, representing the creation of 3 million jobs globally [71]. For consumer plastics, impacts on the environment have been estimated as 3.3–33 USD kg^{-1}, while interventions vary in expenses, with lower costs arising from the implementation of policy measures (0.04–0.06 USD kg^{-1}), intermediate costs from mechanical recycling (0.003–0.23 USD kg^{-1}, depending on informality), and higher costs from mitigation measures, such as implementing trash racks in waterbodies (4.87–8.46 USD kg^{-1}) [72]. Challenges are greater in low-income countries, where waste collection and management systems should be prioritized [73]. Therefore, addressing e-waste also depends upon socioeconomic conditions and resource availability.

3.7. Drivers–Pressures–State–Impacts–Responses (DPSIR) Framework

The current literature review on e-waste microplastics was summarized in a DPSIR framework (Figure 3). DPSIR is used to provide a conceptual understanding of an environmental problem and emphasizes the identification of processes (e.g., drivers, pressures) [12,13]. It complements other analytical tools used in environmental management and assessment, such as life cycle assessment (LCA), which quantitatively compares the environmental performance of a product or process during its life cycle. While LCA is specific for a particular situation at a defined scale (e.g., company, industry, country), DPSIR provides a broader and strategic perspective on an environmental issue [74].

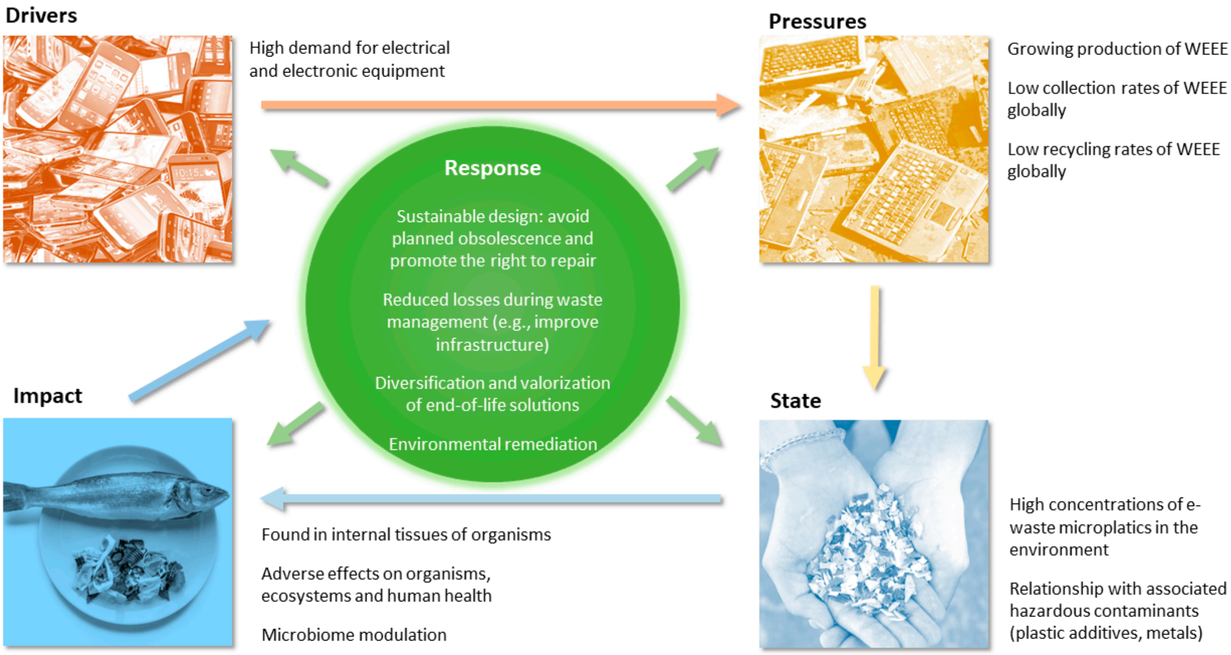

Figure 3. DPSIR (Drivers–Pressure–State–Impact–Response) model for e-waste microplastics.

Concentrations of e-waste microplastics in the environment will increase due to the demand for EEE, lack of appropriate WEEE collection and treatment, and fragmentation of untreated WEEE. As environmental concentrations increase, it is important to develop and establish monitoring protocols for this subclass of microplastics, possibly based on the analysis of traces of metals or additives. E-waste microplastics have already been shown to have adverse effects on organisms, either directly or through pathways also involving associated chemicals.

DPSIR frameworks previously applied to microplastics were summarized in Table 2. Common driving forces include population growth, urban sprawl, high demand for products containing plastics, and regulations promoting the use of plastics (e.g., disposable face masks). Pressures include unplanned land use, insufficient waste collection and treatment, poor wastewater treatment, the release of microplastics from products, the consumption of natural resources in the production of plastics, and the functional use of plastics in many modern-day applications. Similarly, e-waste microplastics result from high demand for EEE and difficulty in using alternatives to plastics with similar properties, such as mechanical resistance and electrical isolation. Despite an increasing demand for EEE, WEEE still lacks adequate collection streams and waste management infrastructure. Moreover, some consumer electronics can have short lifespans, generating large amounts of waste. For instance, the lifespan of mobile phones has been reported to range between 2 and 8 years [75]. A higher reported lifespan may not stem from a longer period of use but instead from a storage period before disposal.

Table 2. Drivers–Pressure–State–Impact–Response (DPSIR) frameworks on microplastics.

Type	Drivers	Pressures	State	Impact	Responses	Reference
E-waste microplastics	– High demand for EEE	– Growing production of WEEE – Low collection and recycling rates of WEE	– High concentrations in the environment – Association with hazardous contaminants (e.g., plastic additives, metals)	– Found in internal tissues of organisms – Adverse effects on organisms, ecosystems, and human health – Microbiome modulation	– Sustainable EEE design – Reduce losses during waste management – Diversification and valorization of end-of-life solutions – Environmental remediation	Present work
Microplastics in rivers in Thailand	– Urban sprawl and lifestyle – High demand for food, housing, and furniture – Online shopping – Health and beauty demands (microbeads in cosmetics)	– Unplanned land use – Insufficient waste and wastewater management	– Changes in the landscape – Accumulation of plastics and microplastics in the environment – Ingestion by organisms	– Economic loss (tourism, aquaculture) – Adverse effects on organisms, ecosystems, and human health	– Land use planning – Improve waste management – Social awareness – Reduce the use of plastics – Circular economy – Policy and regulations – Use of alternative materials – Cleanup activities	Ta et al., 2023 [76]
Microplastics from disposable masks	– Use of face masks for protection during the pandemic – Face masks providing people with safer communication and gathering – Policies promoting face mask use	– Constraints on natural resources – Production of waste – Release of microplastics	– Physical and chemical states of face masks – Release of microplastics from face masks	– Adverse effects on marine organisms and human health – Social and economic impacts (e.g., tourism, food industry)	– Increase awareness – Use of reusable or biodegradable alternatives (e.g., cloth face masks) – Improve management of face mask waste – Reusing and recycling of face masks	Song et al., 2022 [77]
Microplastics in the environment	– Population and economic growth – Production of plastics – Use of microplastics in products (microbeads)	– Resource use – Production of waste – Release of microplastics	– Accumulation of microplastics in environmental compartments – Weathering and interaction of microplastics with other contaminants	– Socioeconomic losses (e.g., tourism) – Adverse effects on organisms, ecosystems, and human health	– Policy and regulation – Education and awareness – Sustainable product design – Improve waste and wastewater management – Biotechnology – Removal in drinking water treatment plants – Environmental cleanups – Other mitigation strategies	Miranda et al., 2020 [78]

Table 2. *Cont.*

Type	Drivers	Pressures	State	Impact	Responses	Reference
Microplastics from building and construction industries	– Population growth – Urbanization – Proximity to coastal areas – Advanced polymer technology	– Consumption of plastic – Production of waste – Degradation of materials – Functional uses in construction	– Distributions and transport between environmental compartments – Release of airborne microplastics	– Exposure through the food chain – Adverse effects on human health	– Policy and regulations – Monitoring – Modern construction technologies – Development of biotechnologies and treatment – Improve ventilation systems	Prasittisopin et al., 2023 [79]

EEE: electrical and electronic equipment; WEEE: waste electrical and electronic equipment.

State generally describes changes in landscape, accumulation of microplastics in the environment, weathering and/or interaction of microplastics with other contaminants, and transport across different environmental compartments. Impacts are mostly comprised of adverse effects on organisms, ecosystems, and human health; economic losses (e.g., tourism, aquaculture); and food safety concerns. Compared to other types, e-waste microplastics are likely to have an increased impact due to their association with other contaminants (e.g., plastic additives, metals). E-waste microplastics are commonly found near waste treatment plants, but few studies have tried to identify them in other areas. They could also act as vectors and expose organisms in the human food chain to high concentrations of contaminants (e.g., metals).

Responses include implementing regulations and policies, increasing social awareness, developing sustainable designs, using alternative materials, improving waste and wastewater treatment, conducting environmental cleanups, implementing measures to reduce human exposure (e.g., air filtration, treating drinking water), and monitoring environmental contamination. Similarly, e-waste microplastics can be prevented through regulations on EEE materials and improved waste management. Recycling may benefit from the high volume of WEEE (e.g., of mobile phones) generated each year, constituting a reliable waste stream. On the other hand, measures could also be implemented to reduce the losses of microplastics during waste treatment and by conducting environmental cleanups.

3.8. Knowledge Gaps in E-Waste Microplastics

The literature on e-waste microplastics is still scarce, currently being limited to 24 studies. The main knowledge gaps identified were (i) the determination of environmental concentrations, (ii) chemical characterization and release of leachates, (iii) modulation of microorganisms, (iv) (eco)toxicological impacts of microplastics and their leachates, and (v) mitigation measures. Priority tasks in the study of e-waste microplastics include the development of identification methods, analysis of the composition of leachates, and the evaluation of toxicity pathways. The toxicity of e-waste microplastics should be further explored through (eco)toxicity studies, also comparing it with common microplastics. Alternative routes of exposure to associated contaminants must be explored. Studies should also be conducted on the potential human health effects of e-waste microplastics, such as the effects of occupational exposure. Finally, more studies must be conducted on mitigation measures that prevent the formation and loss of e-waste microplastics to the environment. These priorities translate into an urgent need for an increased research effort focusing on e-waste microplastics, which is lacking in the current literature and thus limiting risk assessment efforts.

4. Conclusions

E-waste, stemming from a rising demand for electronics, includes a substantial amount of plastics that may fragment into microplastics, posing a threat to the environment. There are many studies on e-waste in general, but few focus specifically on microplastics, so a literature review was conducted based on all available studies on e-waste microplastics (n = 24) found in Scopus and Web of Science, organizing information following the DPSIR framework. This work is based on a systematic review of all available literature in the two databases, which excludes works from non-indexed journals or those found using different keywords. The production of e-waste microplastics is mainly driven by increasing EEE consumption, with the added pressure of lacking an adequate waste management system for e-waste. Fragmentation of plastics in e-waste creates microplastics, which are predominantly found near disposal and disassembly facilities. The lack of analytical methods to identify e-waste microplastics may lead to an underestimation of their amount in other matrices or locations, warranting further development. While e-waste microplastics are associated with contaminants, such as metals and organic compounds (e.g., plastic additives), potentially amplifying toxicity, it remains unclear whether these microplastics act as a significant source of these compounds (or are released simultaneously) and whether their toxicity surpasses that of microplastics from consumer plastics. As supported by the DPSIR framework, e-waste microplastics stand out due to their link to a narrow waste stream, emphasizing the need for regulation of EEE, improved waste management, and mitigation measures. While this framework is suited for identifying global strategies, regional monitoring and other environmental management tools (e.g., LCA) could enhance cost–benefit decision-making, taking into account regional geographical and socioeconomic characteristics. In summary, the growing demand for EEE, combined with insufficient regulation and waste management, underscores the urgent need for measures to prevent the formation of e-waste microplastics.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/environments11020030/s1. Figure S1. Concentration of e-waste plastics in soil (minimum, mean, and maximum) from an e-waste disassembly site in Guiyu, China; an e-waste recycling site in Longtang County, China; and an e-waste dumping site in India. Table S1. Concentration (ppm) of metals in plastics (min–max). PRISMA checklist is also provided in the Supplementary Materials.

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