



# Children and digital dumpsites

E-waste exposure and  
child health



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**World Health  
Organization**

Children and digital dumpsites: e-waste exposure and child health

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# Preface

The burgeoning global market in electronic and electrical devices, combined with shorter device life expectancies, is fuelling an unprecedented health crisis for children in the developing world – exposing them to dangerous chemicals and air pollutants at home, in their communities, and in places where they often work illegally in exploitative and hazardous conditions.

Millions of young children and adolescents, as well as women of childbearing age, work in the growing e-waste dumps of Africa, Asia and Latin America, as well as in some developed economies of Europe and elsewhere, extracting precious metals such as gold from computer chips and copper from cables by burning the devices or using toxic chemical baths. In the process they are exposed to dangerous chemicals such as mercury, lead, dioxins and flame retardants, and breathe air polluted with toxic particles.

In 2019, some 53.6 million tonnes of electronic and electrical waste (e-waste) were generated worldwide, a 21% increase over the past five years. Global e-waste generation is projected to grow to 74.7 million tonnes by 2030.

Debris from such devices is overwhelming landfills in low- and middle-income countries, which receive shiploads of devices and appliances discarded from high-income nations that are avoiding strict domestic rules about device recycling and disposal.

As e-waste dumps expand across the globe, so do the number of workers employed in the e-waste sector.

By 2030, global employment in the waste management sector – which employs some 64 million people today – is projected to increase by some 70%, or another 45 million jobs. Since e-waste is the world's fastest growing waste stream, increasing three times faster than the world's population, many of these jobs, formal or informal, will be in e-waste processing.

E-waste typically includes discarded electronic devices such as computers, televisions, mobile phones, tablets and other video and voice recorders, as well as electrical appliances, both heavy and light.

While large household electrical appliances, such as washing machines and refrigerators, used to be called “durable goods” as they were built to last, the reverse is now often the case. Both large appliances and small devices are often designed in ways that make repairs difficult, and instead encourage frequent device replacement. Yet, it is in the smallest devices that the greatest levels of dangers may lurk, in the form of toxic chemicals such as mercury, polychlorinated biphenyls (PCBs), and lead.

This document is the first comprehensive World Health Organization (WHO) report on the dimensions of the problem; the pathways through which children are exposed; the health effects associated with the different pathways of exposure; and actions that the health sector can take alongside other sectors to confront this new and insidious health risk globally, nationally and locally.

These actions include leadership and advocacy for strong national and local



policies that ensure responsible disposal or recycling of e-waste materials, such as stronger measures to prohibit the dumping of such waste in low- and middle-income countries, capacity-building, stronger monitoring of e-waste exposure in children and the related problem of child labour, and awareness-raising about personal preventive measures. Reducing e-waste upstream through the promotion of “circular economy” measures that ensure more durable and repairable devices is also urgent. Finally, children and women waste workers remain largely invisible in our economies. Better monitoring and tracking of the swelling numbers of waste workers in the informal labour force, and

women and children e-waste workers in particular, is critical to protect those most at risk of exposure, which can lead to a vicious cycle of potentially lifelong, reproductive and developmental health impacts.

With mounting volumes of production and disposal, the world faces what one recent international forum described as a mounting “tsunami of e-waste”, putting lives and health at risk. In the same way the world has rallied to protect the seas and their ecosystems from plastic and microplastic pollution, we need to rally to protect our most valuable resource – the health of our children – from the growing threat of e-waste.



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# Abbreviations

ADHD	attention deficit/hyperactivity disorder
β-HCH	β-hexachlorocyclohexane
BB	brominated biphenyl
BDE	brominated diphenyl ether
BMI	body mass index
BP	bisphenol
BPA, BPAF, BPS	bisphenol A, bisphenol AF, bisphenol S
BPh	bromophenol
CO <sub>2</sub>	carbon dioxide
DDE	dichlorodiphenyldichloroethylene
DP	dechlorane plus
HBCD	hexabromocyclododecane
HCB	hexachlorobenzene
HCH	hexachlorocyclohexane
IARC	International Agency for Research on Cancer
ILO	International Labour Organization
IQ	intelligence quotient
MeO-PBDE	methoxylated polybrominated diphenyl ether
miRNA	microRNA
OECD	Organisation for Economic Co-operation and Development
OH-PAH	hydroxylated polycyclic aromatic hydrocarbon
OH-PBDE	hydroxylated polybrominated diphenyl ether
OH-PCB	hydroxylated polychlorinated biphenyl
PAH	polycyclic aromatic hydrocarbon
PBB	polybrominated biphenyl
PBDD	polybrominated dibenzodioxin
PBDE	polybrominated diphenyl ether
PBDF	polybrominated dibenzofuran
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
PFAS	per- and polyfluoroalkyl substances
PFOA	perfluorooctanoic acid
PFR	organophosphate flame retardant
PM	particulate matter
POP	persistent organic pollutant
PPE	personal protective equipment
S100P	S100 calcium-binding protein P
SDG	Sustainable Development Goal
TBBPA	tetrabromobisphenol-A
UNIDO	United Nations Industrial Development Organization
VOC	volatile organic compound
WHO	World Health Organization

# Glossary

**Child**

WHO defines a “child” as a person under 19 years of age, an “adolescent” as a person aged 10–19 years, an “infant” as a person aged 0–11 months and a “newborn” as a person aged 0–28 days.

**Electrical and electronic waste (e-waste)**

Any electrical or electronic equipment, which is waste, including all components, subassemblies and consumables, which are part of the equipment at the time the equipment become waste.

**Women of childbearing age**

WHO defines “women of childbearing age” as women aged 15–49 years.



# Executive summary

## Digital dumps: e-waste risks to children's health

The soaring global popularity of electronic and electrical devices, from computers to cell phones to heavy appliances, combined with ineffective waste management and disposal, is triggering a crisis of e-waste health risks to which millions of children, as well as women of childbearing age, are exposed.

The problem is most severe in low- and middle-income countries, where significant numbers of impoverished city dwellers work or live near the burgeoning informal dumps and landfills that are the graveyards for much of the world's e-waste, which is defined as any "electrical or electronic equipment, which is waste, including all components, subassemblies and consumables, which are part of the equipment at the time the equipment becomes waste".

E-waste volumes are spiralling. In East and South-East Asia alone the volume of e-waste increased by 63% between 2010 and 2015.

This growing waste stream contains valuable resources such as gold, silver, palladium, platinum, cobalt and copper, as well as bulkier materials such as iron and aluminium. Informal scavenging for e-waste in unmanaged landfills has become an increasingly common source of livelihood, including for women and children.

Informal processing of e-waste through open burning, heating and acid leaching (using cyanide salt, nitric acid or mercury) to extract precious metals exposes children to a range of hazardous compounds, including heavy metals such as mercury, lead and cadmium, as well as other toxic by-products of plastic and metal processing.



Only 17.4% of the 53.6 million tonnes of e-waste produced in 2019 reached formal waste management or recycling systems. The remainder was either disposed of in illegal landfills or recycled by informal workers, domestically or internationally.

And this waste stream is growing every year, driven by consumer habits in high-income countries such as Europe and the United States of America, where the average mobile phone is replaced in less than two years. Based on such estimates, and assuming an average life expectancy of around 70–80 years, an individual could use and dispose of around 30 mobile phones in a lifetime.

This report builds on the WHO Initiative on E-waste and Child Health, updating a systematic review from 2013 with the more extensive knowledge about the issues and

health impacts that have emerged in the past five years.

The report is organized into four main chapters:

1. E-waste trends, settings and exposure pathways
2. Health and development impacts of children's exposure
3. E-waste and health action and policy agenda
4. Way forward: WHO global leadership on reducing health impacts of e-waste exposure.

Key messages from each chapter are briefly presented below.



## Chapter 1. E-waste trends, settings and exposure pathways

### Pathways of exposure

For waste scavengers, toxic exposure occurs through multiple pathways, including:

- ingestion of food, water, soil and dust
- inhalation of aerosol gases and particles
- dermal exposure.

Fetuses and children can also be exposed through unique pathways:

- ingestion of breast milk
- transplacental exposure.

Primitive recycling processes, in combination with the lack of safety measures and personal protection, account for both severe environmental contamination and high risks for the health of workers and people living around e-waste sites.

Hazardous mixtures of e-waste toxicants are released into the environment in the form of airborne particulate matter (PM<sub>2.5</sub>) emitted by dismantling activities, particularly heating and open burning, as well as the leaching of by-products into water sources. Along with heavy metals, other hazardous by-products may include dioxins, furans, flame retardants such as polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs), and polycyclic aromatic hydrocarbons (PAHs). These are all toxic chemicals that are known to cause harm to children.

Hazardous substances may also leach into soil and water, or conversely volatilize from contaminated soil. Dust contaminated by toxic e-waste may be ingested or carried back home into the community by workers on their shoes and clothes.

People are thus exposed to e-waste emissions through multiple routes, including air, soil, dust, water and food, putting at risk even more children and adults, including women of childbearing age, who live near waste sites. They may also be exposed to an array of air pollutants from burning metals and plastics and contaminants transported via local foods, water and soil, or other sources.

Even in cities, where more organized waste management systems exist, e-waste is often discarded by households and businesses along with other solid waste, ending up in landfills. Hazardous substances may leach from discarded e-waste into nearby aquifers and surface water, contaminating drinking-water supplies.

### Children, pregnant women and developing fetuses are among those most at risk

Children and pregnant women working in the informal e-waste recycling industry or living in neighbouring communities are among the most at risk of exposure to hazardous chemicals.

Based on the most recent estimates of the total number of informal waste workers worldwide (12.5–56 million people) and estimates of women labourers in the industrial sector (of which waste is a subsector), estimated at 23% of the workforce, between 2.9 and 12.9 million women may be at risk from exposure to toxic e-waste through their work in the informal waste sector. Regarding children, some 152 million children aged 5–17 years are engaged in child labour, including over 18 million children (11.9%) in industries of which waste processing is a subsector. Some 73 million children worldwide are working in hazardous labour, with still uncounted numbers in the informal waste recycling sector.





## Chapter 2. Health and development impacts of children's exposure

This chapter looks at the hazards causing the greatest risks and the multiple effects of these hazards on children's health.

Prenatal exposure and childhood e-waste exposure are significantly linked with:

- impaired neurodevelopment and behaviour, particularly as a result of exposure to lead, mercury and some organic chemicals such as PCBs;
- negative birth outcomes, which have been associated with chemical exposure, including exposure to PAHs, lead, cadmium, nickel and chromium;
- lung function and respiratory effects, including cough, wheezing and asthma, which have been linked to chromium, manganese and lead exposure;
- impaired thyroid function, especially associated with exposure to some organic chemical compounds, including PCBs and PBDEs;
- impaired cardiovascular system function, in particular in association with exposure to lead and PAHs;
- DNA damage, which has been associated with exposure to lead, chromium, cadmium and nickel;
- impacts on immune system functions, including greater vulnerability to common infections ranging from hepatitis B to ear and respiratory infections, reduced response to immunization from exposure to some organics, greater susceptibility to allergies and autoimmune diseases from exposure to some metals, and immune system suppression correlated with lead and cadmium exposure;

- increased risk of some chronic diseases later in life, including cancer and cardiovascular disease.

Children are particularly vulnerable due to their smaller size, less developed organs and immune systems, and rapid rate of growth and development. For instance, children breathe more rapidly and ingest more food and water relative to their size than adults, thus absorbing relatively higher proportions of pollutants. Children are also less able to metabolize and eliminate hazardous substances from their bodies compared to adults.

Children's behaviour makes them more vulnerable to injury and exposed to hazards. Small children spend more time close to the floor, crawling and playing in dust or dirt. They practise hand-to-mouth and object-to-mouth behaviour more often than adults, increasing the risk of ingesting contaminated dust or soil. As they develop physically and cognitively through infancy, childhood and adolescence, children's behaviour changes and they are susceptible to different injury risks.

While their bodies are undergoing development, including physical growth, increased lung capacity and maturation of reproductive organs, adolescents are also at heightened risks in comparison to adults. Due to lack of training or experience, they may be more accident and injury prone. Older adolescent girls who become pregnant put themselves as well as their fetuses at risk.

For pregnant women working or living near e-waste sites, fetal exposure to toxicants, even at very low doses, during critical developmental windows of gestation when organ systems are developing can have short-term impacts on the pregnancy. Such exposure may also result in long-

term impacts on the health of newborns in childhood or in adult life.

### **Chemicals most closely linked to health impacts**

The most important chemicals detected in e-waste recycling processes belong to the group of 10 chemicals named by WHO as of major public health concern. These include heavy metals such as lead, cadmium, and mercury; persistent organic pollutants such as dioxins; and fine particles (PM<sub>2.5</sub>) and other air pollutants emitted through e-waste combustion.

However, more than 1000 harmful substances have been identified that are either components of e-waste or components of artisanal processing systems. These include not only heavy metals but also PCBs, PBDEs, per- and polyfluoroalkyl substances (PFAS), phthalate esters, organophosphate flame retardants (PFRs), and bisphenols.

E-waste sites are also locations with elevated air pollution resulting from combustion of e-waste materials for extraction of metals. The particulate air pollution is harmful by itself, but also often contains toxic metals and organics.

### **Infectious diseases and e-waste**

The COVID-19 pandemic, which began shortly after the review was completed, has also heightened awareness of infectious disease risks to which informal waste workers, including women and children, are exposed more generally as a result of the poor safety and sanitation issues that they face in their worksites and workplaces. Lack of physical distancing and personal protective equipment increases risk of transmission, and chemical and particulate exposure may increase infection risk. The COVID-19 pandemic has highlighted the need for further research exploring infectious disease risks faced by informal waste workers and their communities.





## Chapter 3. E-waste and health action and policy agenda

This report argues that more assertive action is needed by the global, national and local health sectors in order to place the e-waste issue at the centre of health agendas and stimulate more effective and binding actions by e-waste importers, exporters and governments. Overarching goals should include the following:

- ensuring health and safety of e-waste workers and communities in systems that train and protect workers and monitor exposure and health outcomes, with children's protection of the highest priority;
- sound environmental health practices for disposal, recapture and reuse of materials;
- shifting to a circular economy through manufacture of more durable electronic and electrical equipment, using safer and less toxic materials, and sustainable consumption leading to reduction of e-waste;
- health-conscious and environmentally aware management of e-waste throughout the life cycle, with reference to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, appropriate regional conventions and the Sustainable Development Goals (SDGs) on waste management;
- decent work for e-waste workers across the value chain (collection, processing, recycling and resale), including incorporation of informal workers into the formal economy and the complete elimination of child labour.

The health sector can seize the mantle of leadership and advocacy on the e-waste agenda, and contribute to multisectoral

action, by reaching out to other sectors to demand that health concerns be made central to e-waste policies. Key opportunities for leadership and collaboration include:

- regional and national capacity-building for health-based assessment of e-waste policies and regulations, particularly in terms of children's health;
- awareness-raising among policy-makers, communities, waste workers and their families on health risks and the potential co-benefits of more responsible recycling;
- building health sector capacity, as part of primary health care, to diagnose, monitor and prevent toxic exposure among children and women;
- generating better data and conducting more robust research about the health risks faced by women and children waste workers in the informal sector, and implementing protective measures to mitigate those risks.

### Global and regional level: health sector leadership

Despite a web of international and regional agreements calling for the sound management of e-waste from cradle to grave, including the Basel Convention and the Stockholm Convention on Persistent Organic Pollutants, the transport of e-waste from some high-income countries to some low-income countries remains high.

As a result, United Nations agencies and programmes and experts have recently called for stronger actions based on the severe and growing threat that improperly recycled e-waste presents to human health and the environment.

### **National level: multisectoral collaboration to assess and recommend solutions**

At national level, the health sector can build capacity to assess e-waste hazards, estimate related health costs, and propose contextualized solutions. Policies to encourage safe and efficient recycling also have the potential to reduce health care costs by preventing e-waste-related injuries and other health effects.

In parallel, health systems can set up processes for monitoring and surveillance of toxic exposure among children and women, particularly those of childbearing age, in primary care clinics, and for reporting such exposure to public health authorities. This would greatly enhance the ability of authorities to target exposure hot spots for interventions.

While it is clear that millions of women and children are at risk from e-waste exposure, waste workers also remain largely invisible in national and global statistics collected on the labour market, where waste workers are represented only in the broader category of “industrial” workers (Annex 2).

Better monitoring and tracking of informal waste workers, including e-waste workers,

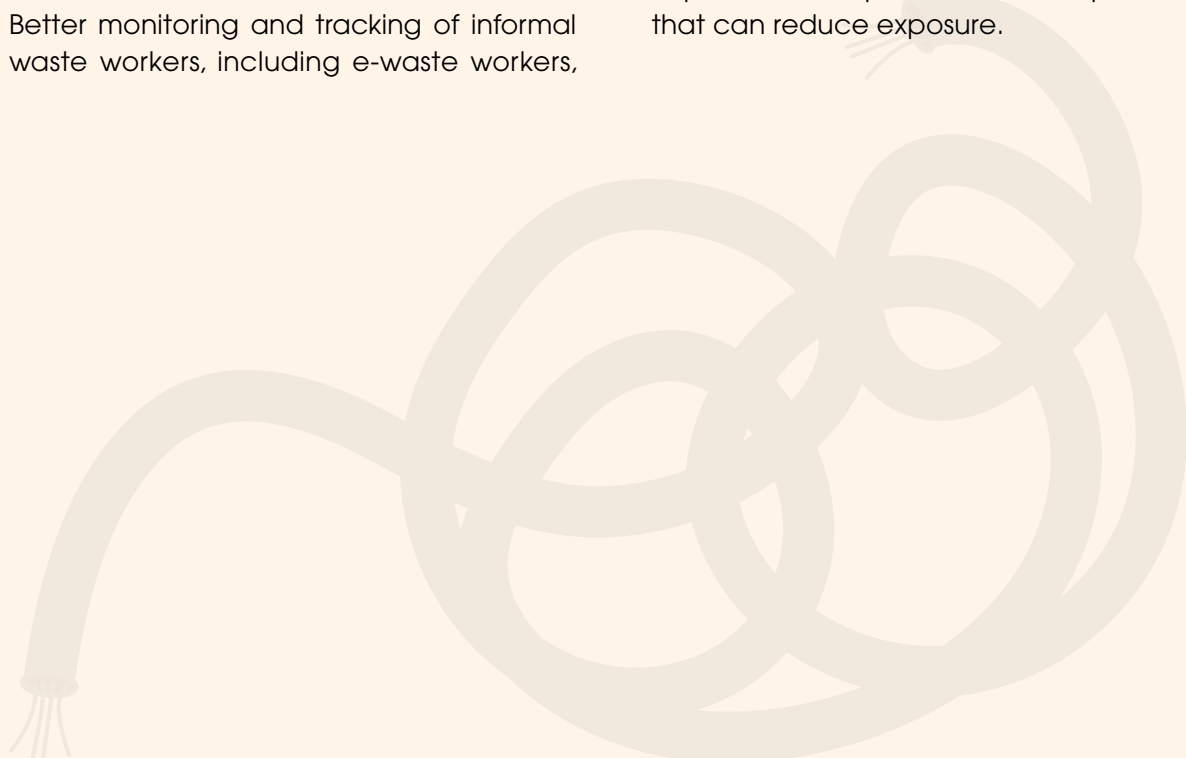
as part of national labour surveys may be one way to make these workers more visible.

Ultimately, multisectoral action is needed to build informed policies, based on knowledge of the national scope of e-waste workers, their exposure to toxic waste, and related health impacts, and solutions that would put e-waste management on a clean development track. Healthier communities and reduction of costs can be obtained from more sustainable and health-focused e-waste policies that stimulate transition to a circular waste economy.

### **Local level: equipping local health care professionals with skills to recognize and address exposure risks**

At the local level, health care professionals need to be trained and equipped to detect exposure to toxic substances, test as feasible for such exposure, and intervene to reduce risks and treat impacts – among children, adolescents and pregnant women.

Health care providers can also take the lead in advocacy and raising awareness in local communities about the risks of e-waste, and improved occupational health practices that can reduce exposure.





## Chapter 4. Way forward: WHO global leadership on reducing health impacts of e-waste exposure

The final chapter discusses the role of WHO in protecting the health of children from the hazards of e-waste. The WHO Initiative on E-waste and Child Health, launched in 2013, set out a range of goals, including increased access to evidence and knowledge, increased awareness about the health impacts of e-waste, improved health sector capacity to identify risks, track progress and promote good e-waste policies that better protect child health, improved monitoring of exposures to e-waste and the facilitation of interventions that protect public health.

Beyond this report, WHO is working with international experts and its global network of WHO collaborating centres on children's environmental health and compiling the existing research and knowledge on e-waste and child health, and is collaborating with other United Nations agencies to create educational and capacity-building materials. Recently, WHO joined the E-waste Coalition, a group of international organizations working globally and supporting national governments to address the e-waste challenge more effectively and across health and environment, climate and development agendas. The work of the

E-waste Coalition aims to spread awareness of e-waste, including producing reports such as the 2020 Global E-waste Monitor, and is guided by the framework set out in the SDGs. The goals of the E-waste Coalition include:

- supporting and strengthening country capacity to manage and reduce e-waste volume, and formulate and implement e-waste management policies and regulations;
- supporting the development of a circular economy;
- increasing awareness and engagement of key e-waste stakeholders at global, regional, national and local levels;
- preventing illegal e-waste trafficking.

WHO's work on e-waste and child health aims to highlight children's right to life, survival and development, which is contingent upon the realization of rights to the highest attainable standard of health and access to a healthy environment, including safe food, water and accommodation.







**1. E-waste trends, settings and exposure pathways**



# E-waste trends, settings and exposure pathways

## 1.1 E-waste trends

The millions of electronic and electrical devices thrown away every year represent the fastest growing global solid waste stream (1) (Figure 1.1). In Europe, the United States of America and China the average mobile phone is disposed of in less than two years (2). Of the 53.6 million tonnes of e-waste discarded in 2019, the United Nations University has estimated that only 17.4% was collected and appropriately recycled (3). Figure 1.2 presents information on the definition and examples of e-waste.

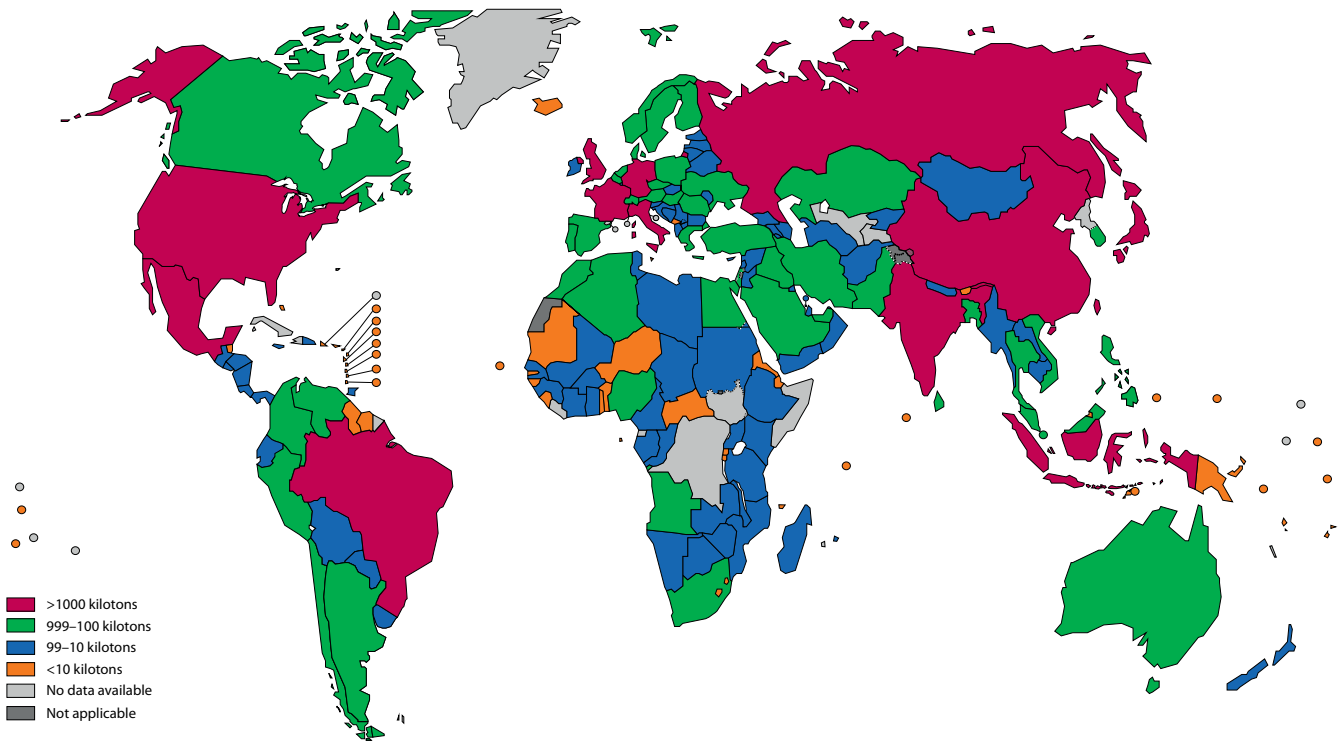
Fig. 1.2

## What is e-waste?

E-waste is any “electrical or electronic equipment, which is waste, including all components, subassemblies and consumables, which are part of the equipment at the time the equipment becomes waste” (4). Such items include:

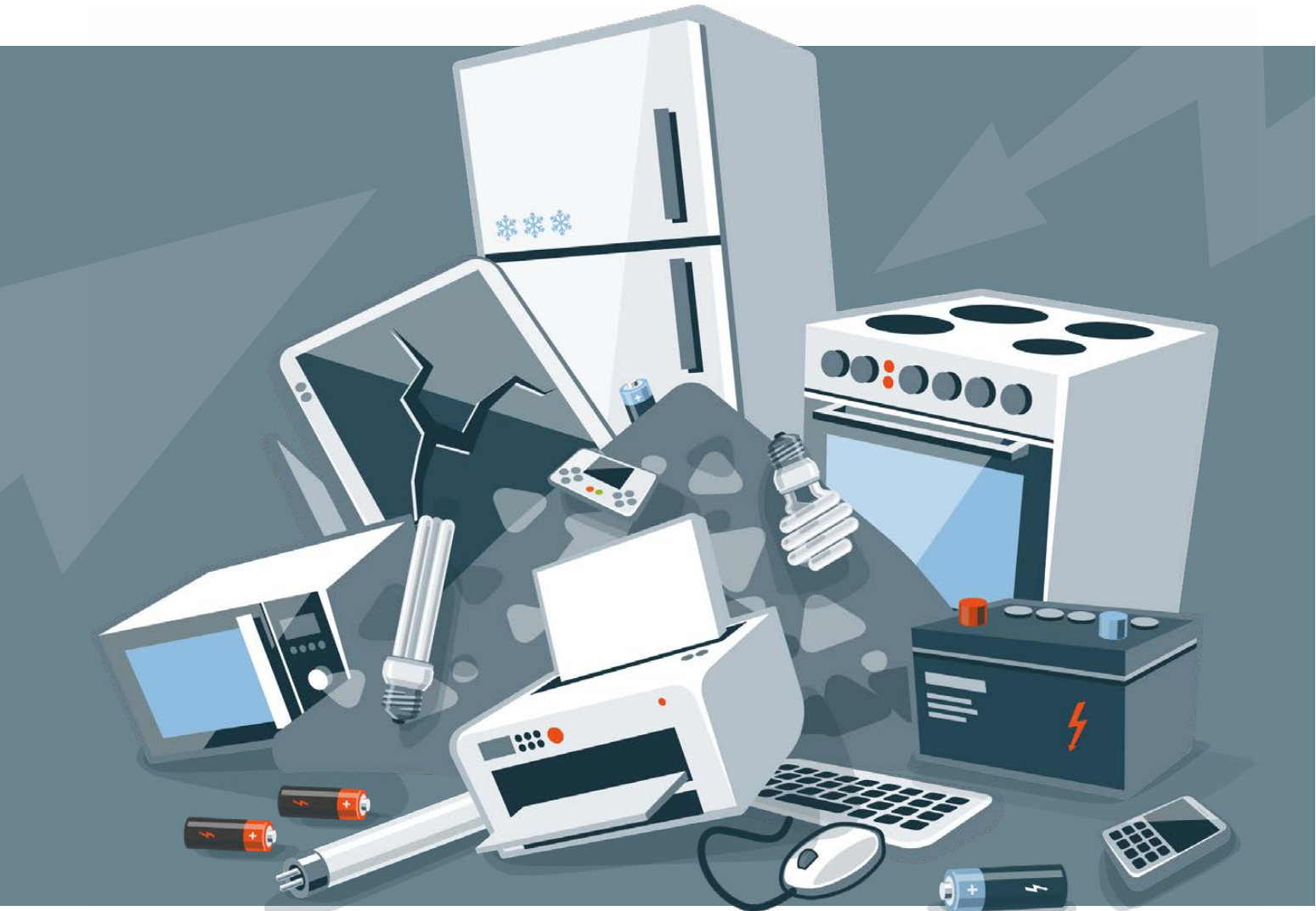
- computers, monitors and motherboards, chips
- wireless devices and other peripheral items
- printers, copiers and fax machines
- telephones, mobile phones and tablets
- video cameras
- televisions
- stereo equipment
- cathode ray tubes
- transformers
- cables and batteries
- lamps and light bulbs (including mercury-containing CFL and fluorescent bulbs)
- large household appliances (refrigerators, washers, dryers, microwaves)
- toys and sports equipment
- tools
- medical devices (some microscopes, electronic blood pressure monitoring devices, electrocardiogram machines, spectrophotometers, etc.) (5–8).





Source: Global E-waste Monitor (3).

**Fig. 1.1**  
E-waste generated by country, 2019



An unknown amount of the remaining 82.6% is processed in a sprawling, globalized informal system of waste recovery sites, located largely in low- and middle-income countries and areas of Asia, Africa and Latin America (Figure 1.3) (3).

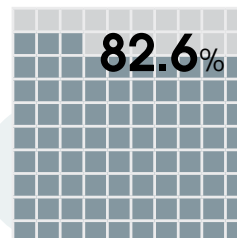
While e-waste is increasingly generated locally in low- and middle-income countries – in East and South-East Asia the volume of e-waste increased by 63% between 2010 and 2015 – the digital debris of advanced economies continues to be shipped abroad to circumvent domestic recycling rules (Figure 1.4) (9, 10). Often, electronic and electrical equipment may be shipped to receiving nations as “second-hand equipment” (10), thus attempting to avoid the scrutiny of the two major global conventions on the transboundary transport and safe disposal of hazardous chemicals and waste – the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, and the Stockholm Convention on Persistent Organic Pollutants. Under the rules of the Basel Convention, such trade may constitute a potential case of illegal movement of hazardous wastes.

Additionally, technological advances continue to create new products with limited life cycles that contain valuable and hazardous materials. For example, electric vehicles currently only make up a fraction of automobiles sold worldwide; however, demand for them continues to grow. Electronic cigarettes (e-cigarettes) are a growing alternative to traditional tobacco cigarettes and are classified as e-waste as they contain lithium-ion batteries, plastics and electronic circuitry equipment that require appropriate recycling (11). A key challenge is how to manage the impacts of e-waste produced by emerging electronic products, such as e-cigarettes and electric vehicles, that contain items with a limited life cycle and toxic components, such as lithium-ion batteries (12).

Once arrived in the destined port of call in Africa, Asia or Latin America, some of the most serviceable devices may be resold. But the remainder are dumped in informal or formal waste sites, ranging from fields or riverbanks to informal e-waste processing centres.

In informal waste management settings, equipment with valuable components is manually dismantled and recycled using primitive techniques, which may include burning, heating or soaking in chemical baths. In the process, toxicants are emitted into the air or leach into soil and water, potentially contaminating entire communities. E-waste workers are directly exposed to a wide range of toxic materials, chemical and combustion fumes, and other residues.

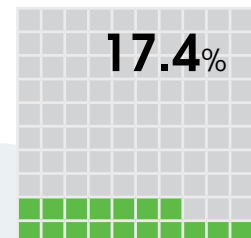
**82.6% or 44.3 Mt of global e-waste produced in 2019 was not documented**



The fate of **43.7 Mt** of e-waste is unknown; this is probably dumped, traded or recycled under inferior conditions

**0.6 Mt** of e-waste is estimated to have ended up in residual waste bins in EU countries

**17.4% or 9.3 Mt of e-waste is documented as collected and properly recycled**

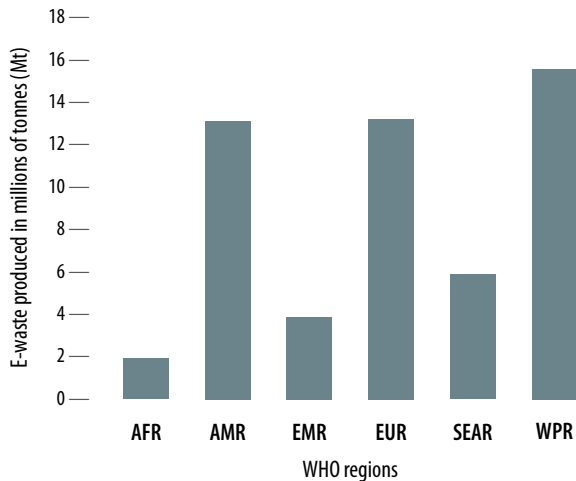


**53.6 Mt of e-waste generated globally in 2019**

Mt = million tonnes

Source: Global E-waste Monitor (3).

**Fig. 1.3**  
**Proportion of e-waste treated in accordance with best available technology**



AFR, African Region; AMR, Region of the Americas; EMR, Eastern Mediterranean Region; EUR, European Region; SEAR, South-East Asia Region; WPR, Western Pacific Region.  
Source: Global E-waste Monitor (3).

**Fig. 1.4**  
**Trends in the generation of e-waste by region**

## 1.2 E-waste settings: an overview

Large informal e-waste dismantling and recycling sites have been reported in the research literature to exist in over two dozen cities or provinces of at least 15 countries, areas and territories across the WHO African, American, Eastern Mediterranean and Western Pacific regions, including Bangladesh, Chile, China, Egypt, Ghana, India, Mexico, Nigeria, Pakistan, the Philippines, Thailand, Uruguay and Viet Nam, as well as in the occupied Palestinian territory, including east Jerusalem. While these sites have been identified through a literature review, the information is not conclusive. Most sites are located in low- and middle-income countries, territories and areas where waste management regulations may be weaker or less strictly enforced. Domestic generation of e-waste in low- and middle-income countries, territories and areas is compounded by large volumes of used and second-hand electronics arriving from abroad (13). But sites also exist in high-income cities, countries, territories and areas, such as Chile, China (Hong Kong Special Administrative Region), and Uruguay (Figure 1.5) (14–42). In the absence of an

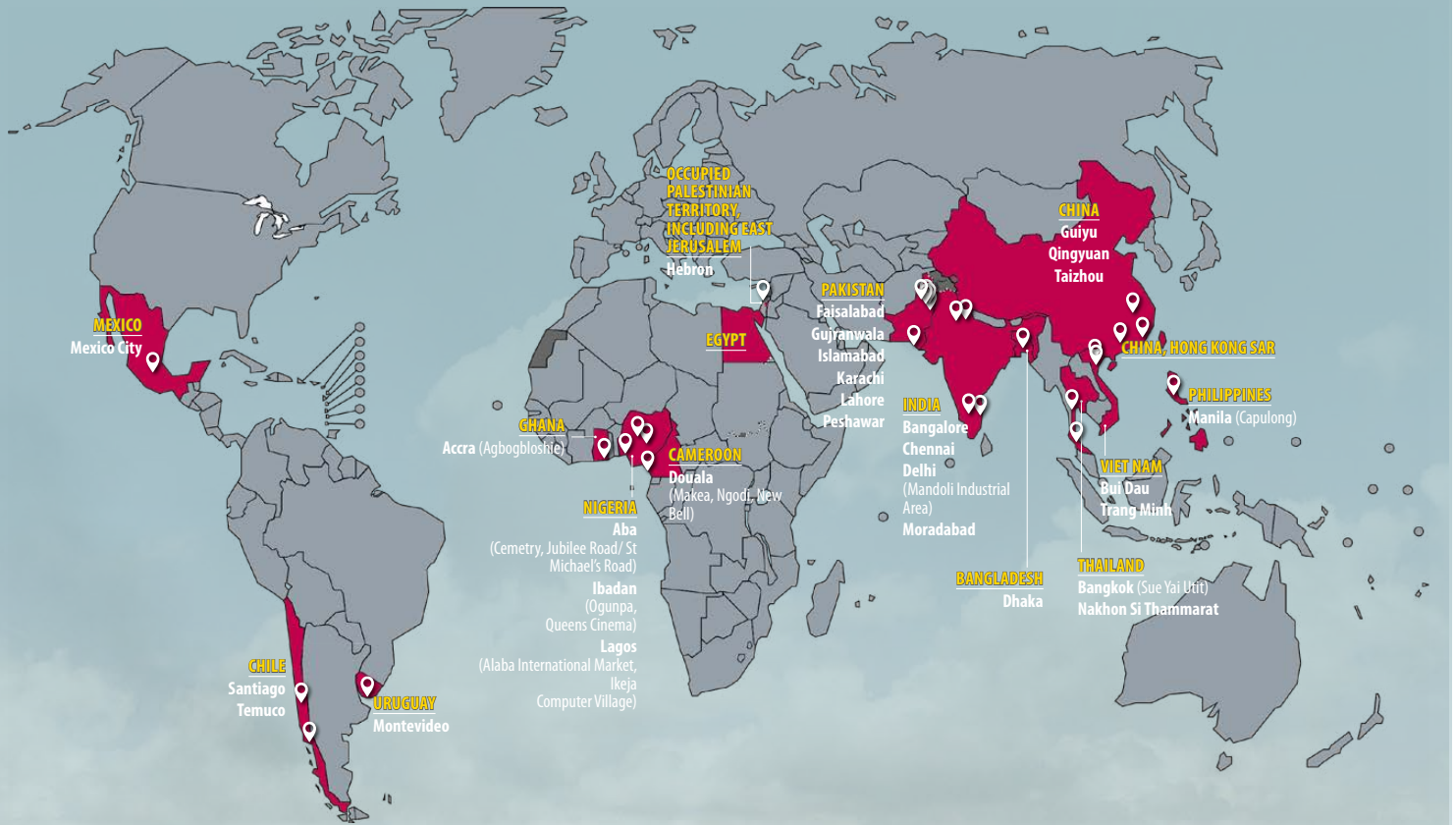
authoritative, global inventory, it is likely that these documented sites may still represent only a fraction of the total sites around the world where waste is informally dumped and processed.

Across different parts of the world, e-waste recycling sites can be very diverse in terms of their size and characteristics.

In Ghana and Nigeria, for example, some sites have developed into entire communities within towns and cities, with distinctive names, such as Agboglobshie e-waste site in Accra, Ghana, a major destination for European e-waste. Around the vast dumpsite dedicated to rudimentary waste scavenging, there are also many workshops and small retail kiosks that refurbish and resell used items and provide skilled apprenticeships to young people aiming to work in the electronics industry.

In comparison, in some Latin American countries, e-waste recycling activity may be more dispersed. Small-scale e-waste recycling activities may be found scattered across neighbourhoods, on street corners and community spaces, as well as within workers' own homes and backyards and involving all family members, including children. With activities more dispersed, vulnerable populations across a city or town may be exposed to pollution from "micro toxic" sites (32, 43–48).

In the Middle East and northern Africa, data on e-waste generation and treatment are scarce, and few assessments of e-waste have been carried out (49). E-waste recycling practices have been reported in a string of villages outside Hebron city, where e-waste workshops are distributed, and are located next to households and schools (40). In the Pacific, concern has arisen over the capacities of small island nations to deal with toxic wastes, including those that come from discarded electronics. In 2001 the Convention to Ban the Importation into Forum Island Countries of Hazardous and Radioactive



**Fig. 1.5**  
Locations of informal e-waste dismantling and recycling sites reported in research literature



**Box 1.1****Building capacity to manage e-waste in Pacific Island countries**

Pacific Hazardous Waste (PacWaste) is responsible for improving hazardous waste management across the Pacific region, including e-waste management. Due to the small populations of many Pacific Island nations and the lack of appropriate and safe infrastructure, concern has arisen over increasing amounts of electronics in the region and how these countries will manage the disposal of e-waste. In 2014, PacWaste conducted a research report into the capacities of five Pacific Island countries to help determine the region's ability to handle e-waste in a manner that is safe for the environment and human health. The aim of the report was to find ways in which PacWaste could effectively work and collaborate with existing structures and organizations in Pacific Island countries to reduce hazardous wastes from electronics. PacWaste found that it could effectively collaborate with national governments and organizations to implement such measures as becoming a party to the Basel Convention, developing takeback systems, raising awareness and increasing training opportunities in safe e-waste dismantling and exporting practices (51, 52).

Wastes and to Control the Transboundary Movement of Hazardous Wastes within the South Pacific Region – known as the Waigani Convention – entered into force and was ratified by 12 countries. This convention bans the importation, and demands regional control over the movement and management, of hazardous and radioactive wastes in Pacific Island countries (50). Box 1.1 presents an example of an e-waste management project in the Pacific region.

### 1.3 Women and children at risk: how many?

Estimates of the numbers of women and children directly at risk from e-waste are hampered by the lack of authoritative global data on both the number of e-waste sites and the number of workers engaged in the informal waste sector.

Global employment in the waste management sector is rapidly increasing. Data suggest that employment in the formal and informal sectors is currently approximately 64 million people, and by 2030 the number of waste workers globally is projected to increase by some 70%, or an additional 45 million jobs (53). Since e-waste is the world's fastest growing waste stream, increasing three times faster than the world's population, many of these jobs, formal or informal, may be in e-waste processing (53).

Another study (54) estimated the global waste workforce, based on a detailed review of 100 studies at national and urban levels, which yielded 43 data sets estimating numbers of informal waste workers in areas, major cities and regions. The assessment yielded an estimate of roughly 12.5–56 million people worldwide working in the informal waste sector.

Yet another review, by the World Bank, puts the figure at 15 million informal waste workers (55), while an International Labour Organization (ILO) review estimates some 19–24 million waste workers worldwide, including 15–20 million in the informal sector (56). While both of these reviews were published more recently, in fact, the data upon which they are based are older and less robust than those used for the 2013 study (54). For a brief review of the data, see Annex 2.

As for women's participation, an estimated 23% of informal workers in the industrial sector, of which e-waste is a part, are women (57, 58), although there are broad variations by country and region (59).

Based on the proportion of women working in the industrial sector more generally, as well as the most detailed meta-analysis of numbers of informal waste workers worldwide, it may be estimated that some

2.9–12.9 million women work in the informal waste sector. Given the rapid expansion of the sector since the last major reviews, it is likely that the actual number is at the upper ceiling of that estimate.

It is important to note that among women of working age, a significant proportion are also in childbearing years, and, at any one time, are also likely to be pregnant during the course of their work. Thus, they and their unborn children are at risk of exposure to toxicants from e-waste directly through working as informal waste pickers or recyclers and from cumulated toxicants, such as lead, that can be passed on during pregnancy.

As for children, some 152 million children aged 5–17 years are working in child labour, including over 18 million children (11.9%) in the industrial sector, of which waste processing is a subsector (60). Some 73 million children worldwide are working

in hazardous labour, with still uncounted numbers in hazardous roles in the informal waste recycling sector (60).

Among the 18 million children employed illegally in various forms of industry, e-waste and its management is a growing branch. Uncounted numbers of those children are thus at risk of exposure to toxic e-waste through their work in the informal waste sector (see Annex 2).

Due to the now ubiquitous presence of e-waste in the local waste stream of low- and middle-income countries, territories and areas, it can be presumed that most of the informal waste workforce is at risk of some level of e-waste exposure, although this may vary from place to place (61). However, even in cities where more organized waste management systems exist, e-waste is often discarded by households and businesses along with other solid waste, ending up in landfills (62, 63).



## 1.4 Pathways of environmental exposure: workplaces, homes and communities

Primitive recycling of e-waste includes open burning of printed circuit boards (boards that connect electronic components in electronic devices), cables and plastics; stripping or burning wires to recover copper; plastic chipping and melting; toner sweeping; and heating and acid leaching (using cyanide salt, nitric acid or mercury) of circuit boards, memory banks or chips to extract gold and palladium. Burning circuit boards by hand is referred to as “cooking” circuit boards. Primitive recycling procedures through open cable burning, acid baths, and cooking circuit boards are considered the most hazardous activities (22, 37, 64, 65). Informal processing of e-waste through these methods exposes children to a range of toxic and hazardous compounds, including mercury, polychlorinated biphenyls (PCBs) and lead (66).

### 1.4.1 Children’s exposure as labourers in waste sites

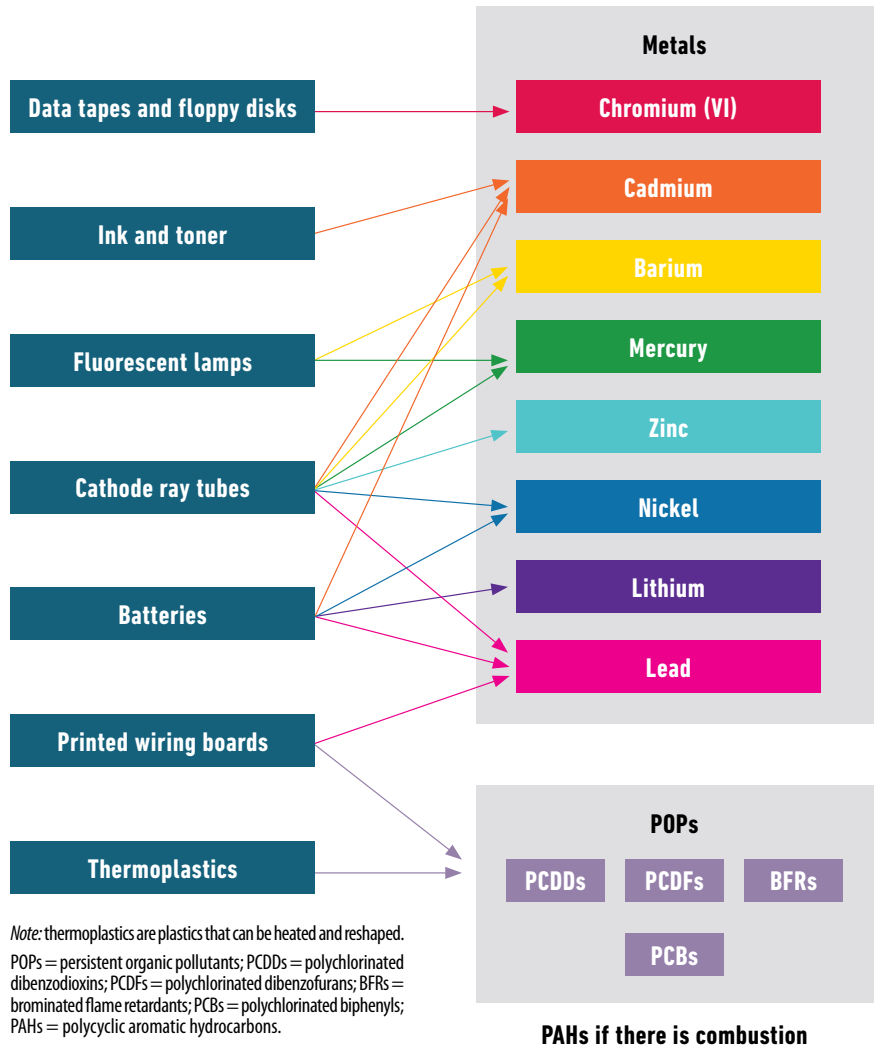
With their smaller hands, children can dismantle intricate electronics. Children who work with e-waste are often involved in the manual sorting of electronics from mixed waste. Children as young as 5 years of age work in the sorting, dismantling and recycling of e-waste (67–69). Predominantly male children and adolescents are involved in e-waste work in Agbogbloshie, Ghana (67, 70). Young waste pickers, who salvage recyclable materials from waste sites, may also come into contact with e-waste. Their age and inexperience make them a source of cheap labour and less empowered to press for better working conditions.

### 1.4.2 Children’s exposure in home settings, and via family members

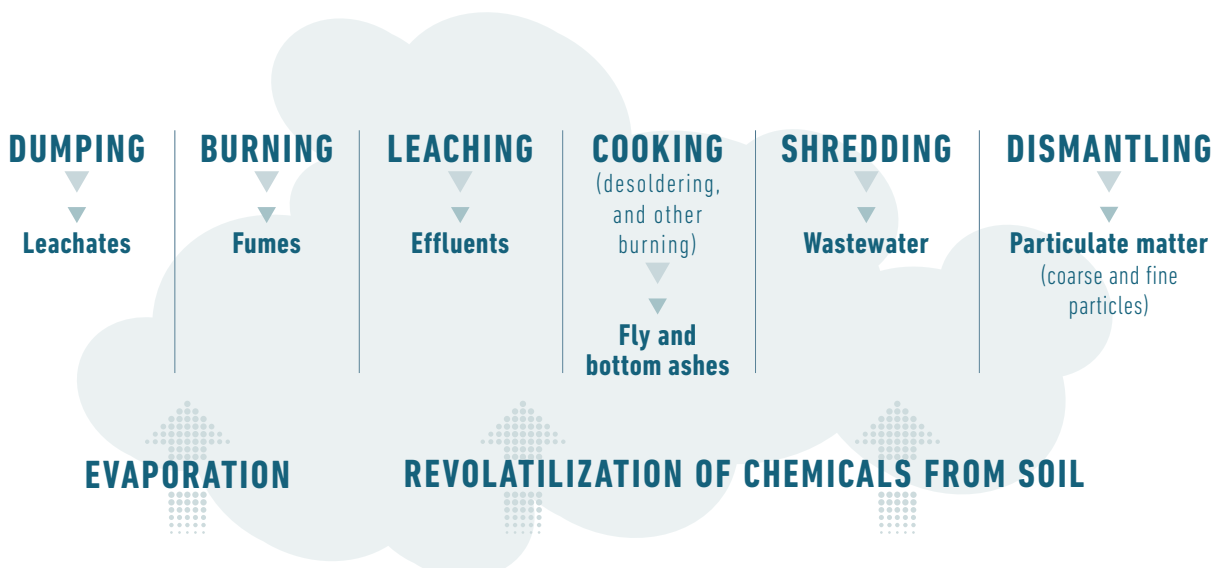
Even if they are not involved in recycling themselves, children live in home-based family workshops and communities where such e-waste recycling takes place (56). Dismantled electronics stored in homes, gardens and play areas are an injury risk to young children who are exploring their world and do not understand hazards. Children are particularly at risk of chemical burns; burns from fires lit to strip wire; unintentional poisoning from corrosive agents used to leach gold from circuit boards; and cuts and falls from handling dismantled electronics.

Extremely high levels of contaminants have been recorded on the floors and surfaces, and in the soil and air, of e-waste recycling sites where crude material recovery techniques are used (17, 71–75). Given that young children show much greater hand-to-mouth activity than older children, contamination of floors and soils pose particular risk to them. In the absence of appropriate safeguards, hazardous chemicals from e-waste, as well as substances such as lead, acid or mercury extracted or used in extraction processes, may be carried from workplaces on skin, clothing, food and containers back to homes and communities (17, 71–73). Family members working at e-waste sites thus risk exposing children or pregnant women to contaminants that they carry home (64, 76, 77).

Figure 1.6 presents information on common toxicants released from unsound waste management activities (7, 65), while Figure 1.7 shows hazardous emissions from informal recycling activities (64, 65, 78).



**Fig. 1.6**  
Common toxicants released from unsound waste management activities



**Fig. 1.7**  
Hazardous emissions from informal recycling practices



### 1.4.3 Community environmental exposure

Beyond the direct, occupational exposure in workplaces and homes, communities around waste sites are exposed to toxic air pollutants from burning metals and plastics, as well as contaminants transported via local foods, water and soil, or other sources. The dispersal of harmful material through these means exposes children as well as women who are pregnant, nursing or of childbearing age.

E-waste may leach hazardous substances into nearby aquifers and surface water, contaminating drinking-water supplies of areas that may be far beyond the immediate communities in close proximity to e-waste sites (78).

Dumping or leaching of acid used to extract gold and other valuable metals into rivers is common (61, 71, 75). Rain and flooding can create run-off from e-waste stored outside (79) or at dumping sites. Multiple studies have reported high levels of e-waste contaminants in water bodies near recycling sites (71, 79, 80).

Burning, removing soldered components, cooking, and dismantling of electronic components create particulate matter, fumes and ashes that contribute to ambient air pollution. While concentrations of pollutants may be highest at the e-waste site, particles and gases can also drift considerable distances across neighbourhoods and cities.

WHO examined the results of a multidisciplinary analysis of particulate matter from other sources and found that ultrafine particles of PM<sub>1</sub> (particulate matter less than 1 micrometre in diameter) or less may travel up to tens of kilometres; fine particles of PM<sub>2.5</sub> or less may travel hundreds to thousands of kilometres; and coarse particles up to PM<sub>10</sub> in size may travel up to hundreds of kilometres (81).

Chemical residues, such as polycyclic aromatic hydrocarbons (PAHs) and volatile

organic compounds (VOCs) in soils and landfills, may also evaporate or volatilize.

Environmental pollution can thus lead to the long-range transport of chemicals through air, water, soil and food contamination. One study in India found that informal e-waste recycling is a major contributor to local air pollution (23). Some chemicals in e-waste can persist in soil and can be ingested by animals (68). Over time they bioaccumulate in livestock and can be ingested by humans through dairy products, meat, fish, shellfish and eggs. The highest ever reported levels of brominated dioxins in eggs were found in chicken eggs from Agbogbloshie, Ghana (82). Rice grown in paddy fields near e-waste sites may contain metals from e-waste toxicants in the soil, even after e-waste sites have been abandoned (83).

Methylmercury accumulates in fish and shellfish and is the primary source of exposure in the general population. People living or working at e-waste sites may be exposed to mercury from both electronic items and methylmercury from fish and shellfish consumption (84, 85).

Fine particles of black carbon produced from the burning of waste are also short-lived climate pollutants. It is estimated that rapid reductions of black carbon emissions could slow global warming by as much as 0.5°C by 2050, in so far as these pollutants only live in the atmosphere for a period of weeks or months – as compared to hundreds of years for CO<sub>2</sub> (86).

Box 1.2 presents an example of soil pollution from e-waste recycling in India.

### 1.4.4 Mapping key toxicants, exposure pathways and toxic effects

Table 1.1 maps some of the key hazardous components of e-waste that may contaminate air as aerosols or particulate matter or persist in soil and water and potentially contaminate food supplies.

**Box 1.2****Elevated levels of polychlorinated biphenyls (PCBs) in soil associated with informal e-waste recycling in Indian cities**

India has emerged as a major importer and producer of e-waste. Of the total amount of e-waste produced in India, an estimated 95% is recycled in the informal sector. Recent studies of soil samples from four of India's major e-waste recycling hot spots – New Delhi, Kolkata, Mumbai and Chennai – have revealed an association between informal recycling and elevated levels of toxic PCBs in soils in surrounding metropolitan areas. The study found that 90% of the soil samples taken from 28 different e-waste sites across these four cities were contaminated with 26 PCB compounds. Among these sites, Chennai dumpsites displayed the highest soil levels of plasticizers, bisphenol A (BPA) and copper. This research hypothesizes that this may be due to the major automobile industry located in Chennai and open burning practices (87, 88).



**Table 1.1**  
**Hazardous substances present in waste electrical and electronic equipment: sources and routes of human exposure**

Hazardous substance	Component of electrical or electronic equipment (5, 66)	Ecological source of exposure (66)	Main toxic effects in humans (5)
<b>Metals</b>			
Lead (Pb)	Printed circuit boards, cathode ray tubes, light bulbs, televisions, batteries	Air, dust (ashes), water, soil	Neurodevelopmental Renal Cardiovascular Reproductive (66)
Chromium (Cr) or hexavalent chromium	Anticorrosion coatings, data tapes, floppy disks	Air, dust, water, soil	Cancer (Cr VI) Allergy
Cadmium (Cd)	Printer inks, toners, photocopying machines (printer drums), switches, springs, connectors, printed circuit boards, batteries, infrared detectors, semiconductor chips, cathode ray tubes, mobile phones	Air, dust, soil, water, food (especially rice and vegetables)	Renal Bone
Mercury (Hg)	Switches (82), thermostats, sensors, monitors, cells, printed circuit boards, cold cathode fluorescent lamps, LCD screens	Air, vapour, water, soil, food (methylmercury bioaccumulates in fish and shellfish)	Neurodevelopmental Renal
Nickel (Ni)	Batteries, cathode ray tubes	Air, soil, water, food (plants)	Allergy Liver (66)
Lithium (Li)	Batteries	Air, soil, water, food (plants)	Lung damage (66)
Barium (Ba)	Cathode ray tubes, fluorescent lamps	Air, water, soil, food	Neurodegenerative disease (66)
Beryllium (Be)	Power supply boxes, computers, X-ray machines, ceramic components of electronics	Air, food, water	Cancer (66) Lung disease (66)

**Table 1.1**  
**Hazardous substances present in waste electrical and electronic equipment: sources and routes of human exposure,** continued

Persistent organic pollutants (POPs)			
<b>Brominated flame retardants</b> Polybrominated diphenyl ethers (PBDEs) Polybrominated biphenyls (PBBs) Tetrabromobisphenol-A (TBBPA) Per- and polyfluoroalkyl substances (PFAS)	Added to materials, especially plastics (thermoplastic components, cable insulation), of computers	Air, dust, food, water, soil	DNA damage (79) Endocrine disruption Reproductive Negative birth outcomes (66) Cancer (66) Neurodevelopmental
Polychlorinated biphenyls (PCBs)	Dielectric fluid in electrical equipment, particularly capacitors and transformers, in heat transfer fluids	Air, dust, soil, food (bioaccumulative in fish and seafood)	

## 1.5 Physiological routes of exposure

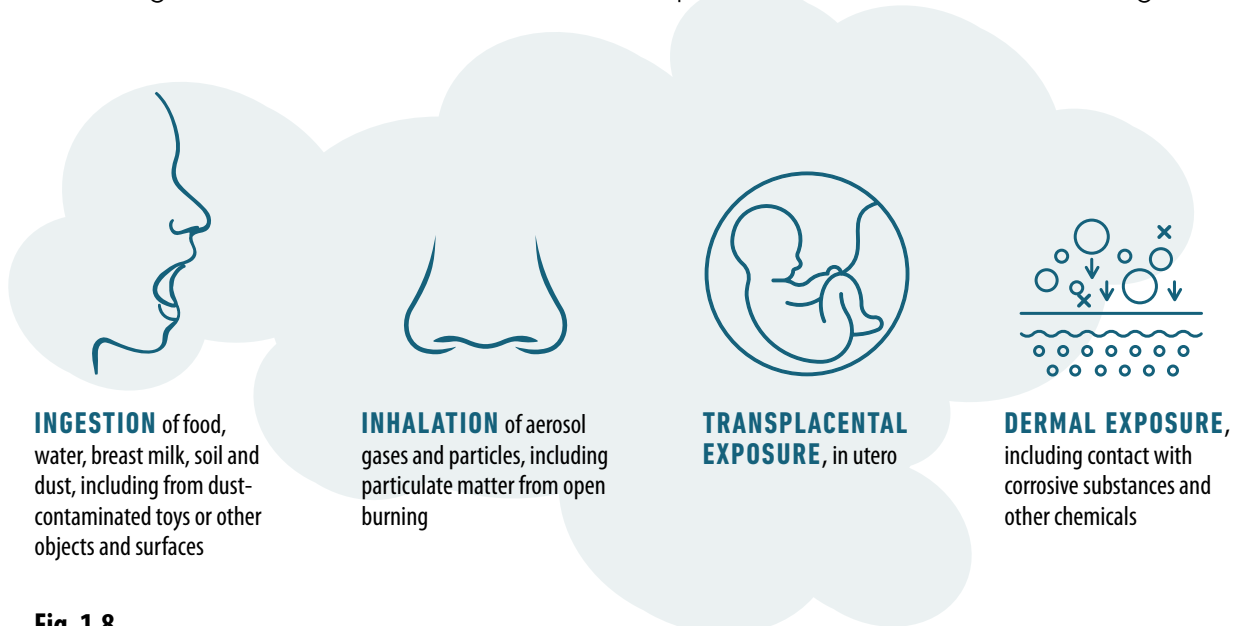
There are four major physiological pathways of children's exposure (Figure 1.8):

- ingestion of food, water, breast milk, soil and dust, including from dust-contaminated toys or other objects and surfaces;
- inhalation of aerosol gases and particles, including particulate matter from open burning;

- transplacental exposure, in utero;
- dermal exposure, including contact with corrosive substances and other chemicals.

### 1.5.1 Ingestion

Ingestion is the primary route of children's exposure to e-waste contaminants in home and community settings (37, 89). Leachate from e-waste recycling and chemicals such as acid and cyanide used during the recycling process can contaminate drinking-water,



**Fig. 1.8**  
**Physiological routes of exposure**

crops, livestock and aquatic animals (64). Crops, such as rice, are grown in some areas where informal e-waste recycling occurs (64). Shellfish, fish, red meat, milk and eggs are of particular concern because some chemicals – for example, PBDEs, PCDDs, PCDFs, polybrominated dibenzodioxins (PBDDs) and polybrominated dibenzofurans (PDBFs) – can accumulate in their tissues (64). In two studies of e-waste recycling in areas of China, levels of PBDEs in fish and shellfish were between 10 and 15 000 times higher than those in other areas of the world (90, 91).

The ingestion of household dust and contaminated soil also poses a risk, as children practise more hand-to-mouth and object-to-mouth behaviour than adults. One study in an e-waste area found exposure to heavy metals from ingestion of dust two to three orders of magnitude greater than exposure from inhalation in children (89).

Infants may be exposed to contaminants in their mother's breast milk as well as in the home and community environment in which they live. Breast milk contains a high concentration of fat, and lipophilic chemicals found in the mother's body will be present in the fat. There is evidence that PCBs, PBDEs and hexabromocyclododecanes (HBCDs) can be transferred to infants via breast milk (18, 92, 93). Exclusive breastfeeding up to the first six months, and continued breastfeeding with complementary foods for two years and beyond, is recommended by WHO as the best source of nutrition for children (94).

### 1.5.2 Inhalation

Inhalation is a critical route of exposure to e-waste pollutants that are burned, heated or subjected to chemical reactions. These include particulate matter, PAHs, dioxins, furans, PCBs and brominated flame

**Table 1.2**  
**Hazardous substances released during e-waste combustion**

<b>Chemicals released during combustion of waste electrical and electronic equipment</b>	<b>Released as (5)</b>	<b>Pathways of exposure (66)</b>	<b>Main toxic effects in humans (5)</b>
<b>Persistent organic pollutants</b>			
Polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs)	Combustion by-products	Air, dust, water, soil	Endocrine disruption Cancer Neurobehavioural
Polychlorinated biphenyls (PCBs) Per- and polyfluoroalkyl substances (PFAS) Polybrominated diphenyl ethers (PBDEs)	Combustion by-products (also found in dielectric fluids, lubricants and coolants in generators, capacitors and transformers)	Air, dust, water, soil	
<b>Polycyclic aromatic hydrocarbons (PAHs)</b>			
Acenaphthene Acenaphthylene Anthracene Phenanthrene Fluorene Fluoranthene Benz[a]anthracene Chrysene Naphthalene Pyrene Benzo[a]pyrene Benzo[b]fluoranthene Benzo[k]fluoranthene Dibenz[a,h]anthracene Benzo[g,h,i]perylene Indeno[1,2,3-cd]pyrene	Combustion by-products	Air, dust, soil, food	Cancer Respiratory (66)

retardants released from the burning of e-waste materials. Children are at greater risk from inhalation because of their higher breathing rate than adults. The daily intake of PCDDs and PCDFs from inhalation at e-waste sites in China was estimated to be almost twice as high for children as for adults (37). Table 1.2 lists the most common by-products generated by combustion of e-waste.

### 1.5.3 Transplacental exposure

Exposure of pregnant women, even to low doses of toxicants, puts their fetus and newborn child at risk during critical developmental windows of gestation and early childhood when organ systems are developing.

Toxic chemicals in e-waste can be transferred from mother to fetus during pregnancy. There is evidence that PCBs, phthalates, flame retardants, phenols, PFAS, mercury, lead, cadmium, chromium, arsenic and zinc can cross the placenta (95–97). Although there is evidence that metals are detoxified by the placenta at different rates through pregnancy, there are still gaps in understanding how each chemical is transported and stored in the placenta, and its impact on placental function (98).

Exposure may start even earlier, at conception, as toxic chemicals such as lead, cadmium, metabolites and PCBs have been detected in semen (99).

### 1.5.4 Dermal exposure

Dermal exposure can occur when hazardous substances are absorbed by the skin, as is common for lipophilic organic compounds, or sit on the surface of the skin (100). There is growing evidence that the skin barrier is not fully developed until 2 years of age (100–102). Premature babies are especially vulnerable because their skin is more fragile, and the skin barrier protection is less developed than in full-term infants (100). Dermal exposure is also

the route by which biological contaminants enter the body when a child is injured, for example by a sharp e-waste object.

## 1.6 Children's special vulnerability and susceptibility

Children's developmental status and behaviour make them particularly vulnerable to e-waste exposure via the multiple pathways addressed here.

Children breathe more air and ingest more food and water relative to their size than adults (103). As a result, children have higher intakes of pollutants relative to their size than adults (89). Children's bodies metabolize and eliminate toxic substances differently compared to adults. Children's bodies are not able to break down some hazardous substances and eliminate them (103).

Children are also more vulnerable to infection and injury. For instance, small children spend more time on the floor, and thus may be forced to crawl or play around e-waste debris or dust. They breathe air closer to the ground, where air pollution may also be of the highest concentration (104). Small children are likely to put their hands, objects and soil in their mouths, increasing their risk of ingesting contaminants (68, 104, 105). Children with pica – compulsive ingestion of non-food items – are at the highest risk.

Infancy and childhood are critical periods of neurodevelopment, when neuronal growth, differentiation, migration, synaptogenesis, and myelination are taking place (84). The respiratory system is particularly vulnerable to exposure both during pregnancy and in the early years of life, which can impact the structural development and function of the lungs (106, 107).

Infants need constant supervision and small children are not able to move about

independently; therefore, caregivers cannot easily distance them from homes or sites where e-waste is being dismantled. At the same time, infants and toddlers do not recognize common injury risks. Older children and adolescents employed in waste sites often do not have the experience to recognize unsafe work conditions or the status to request better conditions (68).

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**2.  
Health and  
development  
impacts of  
children's  
exposure**



## Health and development impacts of children's exposure

There is a growing body of research showing that exposure to toxic contents of e-waste impacts multiple organs of the body and multiple biological systems simultaneously, and that infants and children are at high risk of health effects due to their special vulnerabilities, as described in Chapter 1. The information presented here is derived from the most recent studies on the health effects of e-waste, as well as studies of health effects from individual chemical exposures, regardless of their origins in e-waste or other pollution sources.

The first systematic review of e-waste and health effects, published in 2013, concluded that evidence was suggestive of an association between e-waste exposure and the following health outcomes: reduced thyroid function; altered cellular expression and function; adverse neonatal outcomes; adverse changes in children's temperament and behaviour; and decreased childhood lung function (1).

Recent studies support these findings and also support the conclusion that there is an association between exposure to e-waste and DNA damage (2), immune system dysfunction, adverse neurodevelopment and behavioural outcomes, endocrine disruption, and chronic diseases later in life (such as cancer, diabetes and cardiovascular disease) (3). Table 2.1 shows a summary of the health effects studied in the new literature used to write this report.

In 2016, a review of health outcomes in children exposed to heavy metals from e-waste sources suggested that such exposure could impact multiple organ systems (4). This is supported by extensive research of the effects of heavy metals in non-e-waste settings (see Table 2.2). For a more detailed analysis of the research used in this report please see the supplementary literature review published online.

Although the body of research has grown in the last decade, many human studies have focused on exposure assessment rather than health outcomes. As a result, a causal relationship between e-waste exposure and any specific health outcome cannot yet be established due to the heterogeneity of study design, including the diversity of exposure indicators, the size of the population and the specific health outcomes studied. In addition, children at e-waste sites are exposed to mixtures of different chemicals. There are significant challenges in studying health effects of chemical mixtures, so most studies focus more narrowly on a small number of individual chemicals. There is a dearth of long-term studies that could better define how childhood exposure impacts health later in life, particularly the burden of noncommunicable diseases. In spite of these limitations, there is extensive literature on the health effects of the chemicals that are found at e-waste sites, allowing identification of expected disease outcomes even when there is inadequate study of the health outcomes of children exposed to e-waste chemicals.

**Table 2.1**  
**Literature review: health effects of exposure to e-waste, by health outcome**

Author	Exposure location	Exposure setting	Exposed population	Primary toxicant	Health outcome
<b>Short-term health effects, stress, injuries</b>					
Decharat S. (5)	Nakhon Si Thammarat province, Thailand	Informal recycling workers versus office staff	Informal recycling workers (aged 18–57 years). Exposed ( $n=54$ ), control ( $n=25$ )	Mercury	Urinary and airborne mercury levels significantly correlated. The prevalence of insomnia, muscle atrophy, weakness and headaches were all statistically higher among the exposed group.
Feldt T et al. (6)	Agbogbloshie, Ghana	Informal recycling workers vs residents of control urban area	Informal recycling workers. Exposed ( $n=72$ ), control ( $n=40$ )	PAHs	PAH metabolites significantly higher in exposed individuals compared to non-exposed individuals. Higher urinary PAH levels found in individuals exposed to e-waste recycling processes.
Yohannessen K et al. (7)	Santiago and Temuco, Chile	Informal vs formal recycling workers	Informal recycling workers ( $n=78$ ), formal recycling workers ( $n=15$ )	Not assessed	Workers generally reported good health, prevalence of chronic diseases reported was comparable to national levels. Few health differences reported between informal and formal workers.
<b>Adverse neonatal outcomes</b>					
Xu L et al. (8)	Guiyu, China	Exposed town vs control town	Pregnant women and newborn infants. Exposed pregnant women ( $n=99$ ), control ( $n=86$ )	Lead, cadmium	Cadmium negatively correlated with both neonatal weight and length.
Xu L et al. (9)	Guiyu, China	Exposed town vs control town. Some participants employed in e-waste recycling	Pregnant women and newborn infants. Exposed pregnant women ( $n=69$ ), control ( $n=86$ )	PBDEs	PBDE concentration negatively correlated with head circumference and neonatal body mass index (BMI) and strongly negatively correlated with Apgar 1 score. Same study population as Xu L et al. (8).
Zhang Y et al. (10)	Guiyu, China	Exposed town vs control town. One participant did work related to e-waste during pregnancy	Pregnant women and newborn infants. Exposed pregnant women ( $n=237$ ), control ( $n=212$ )	Cadmium	Maternal urinary cadmium levels significantly higher among mothers from exposed group. Exposed mothers with female neonates had higher cadmium levels than those with male neonates. Maternal urinary cadmium level correlated with significant decrease in birth weight, neonatal BMI, head circumference and Apgar score at 1 minute, but increased birth length in male and female neonates and significant increase in gestational age in male neonates only.

**Table 2.1**  
**Literature review: health effects of exposure to e-waste, by health outcome, continued**

Author	Exposure location	Exposure setting	Exposed population	Primary toxicant	Health outcome
Huo X et al. (11)	Guiyu, China	Exposed town vs control town	Pregnant women. Exposed ( $n=155$ ), control ( $n=102$ )	Hydroxylated PAH (OH-PAH)	PAHs associated with a decrease of 234.56 g in weight, 1.72 cm in head circumference, 1.06 kg/m <sup>2</sup> in BMI, 0.42 in Apgar 1 score.
Li M et al. (12)	Guiyu, China	Exposed town vs control town	Pregnant women. Exposed ( $n=150$ ), control ( $n=150$ )	PBDEs	Neonatal head circumference, BMI and Apgar 1 score negatively correlated with PBDE concentration.
<b>Short placental telomere</b>					
Li S et al. (13)	Guiyu, China	Exposed town vs control town	Newborn infants. Exposed ( $n=220$ ), control ( $n=93$ )	Cadmium, lead	Cord blood cadmium negatively correlated with placental telomere length.
<b>Growth</b>					
Xu X et al. (14)	Guiyu, China	Exposed town vs control town	Children (aged 3–7 years). Exposed ( $n=95$ ), control ( $n=72$ )	PAHs, lead	Child height and child chest circumference associated with PAHs.
Xu X et al. (15)	Guiyu, China	Exposed town vs control town	Children (aged 3–7 years). Exposed ( $n=415$ ), control ( $n=296$ )	Chromium	Positive correlation between blood chromium and body weight and chest circumference, especially in boys.
Zeng X et al. (16)	Guiyu, China	Exposed town vs control town	Preschool children. Exposed ( $n=300$ ), control ( $n=170$ )	Lead, cadmium, chromium, manganese in PM <sub>2.5</sub>	Blood lead negatively associated with height, weight, head circumference and chest circumference. No significant differences in blood chromium or manganese.
<b>Neurodevelopment, learning and behavioural outcomes</b>					
Cai H et al. (17)	Guiyu, China	Exposed town vs control town	Children (aged 3–6 years). Exposed ( $n=358$ ), control ( $n=16$ )	Lead	Blood lead correlated with decreased serum cortisol and an increase in child sensory integration difficulties.
Liu L et al. (18)	Guiyu, China	Exposed town vs control town	Children (aged 3 years). Exposed ( $n=135$ ), control ( $n=149$ )	Lead	Blood lead negatively correlated with cognitive scale scores and language scale scores.
Liu L et al. (19)	Guiyu, China	Exposed town vs control town	Children (aged 3 years). Exposed ( $n=135$ ), control ( $n=149$ )	Lead, cadmium	Lead negatively correlated with cognitive and language scores. The same study population as Liu et al. (18).
Liu W et al. (20)	Guiyu, China	Exposed town	Children (aged 3–7 years). ( $n=240$ )	Lead, cadmium, manganese	Serum S100 $\beta$ levels associated with heavy metal levels in blood and may be linked to certain behavioural abnormalities.
Zhang R et al. (21)	Guiyu, China	Exposed town	Children (aged 3–7 years) ( $n=243$ )	Lead, cadmium	Children with high blood lead levels had 2.4 times higher risk of attention deficit/hyperactivity disorder (ADHD) than those with low blood lead levels. No correlation between cadmium and ADHD behaviours.

**Table 2.1**  
Literature review: health effects of exposure to e-waste, by health outcome, continued

Author	Exposure location	Exposure setting	Exposed population	Primary toxicant	Health outcome
<b>Immune function</b>					
Cao J et al. (22)	Guiyu, China	Exposed town vs control town	Preschool children. Exposed ( $n=62$ ), control ( $n=56$ )	Lead	Blood lead level positively correlated with percentage of peripheral CD4 <sup>+</sup> and CD8 <sup>+</sup> central memory T cells. Lead may contribute to increased percentage of peripheral CD4 <sup>+</sup> central memory T cells.
Dai Y et al. (23)	Guiyu, China	Exposed town vs control town	Preschool children (aged 2–6 years). Exposed ( $n=332$ ), control ( $n=152$ )	Lead	Erythrocyte lead and blood lead linked to the disadvantageous changes in Hct, MCV, Hgb, MCH, and MCHC.
Huo X et al. (24)	Guiyu, China	Exposed town vs control town	Preschool children (aged 2–7 years). Exposed ( $n=132$ ), control ( $n=135$ )	Lead	High erythrocyte lead concentrations were significantly related to lower erythrocyte CD44 and CD58 expression.
Li R et al. (25)	Northern China	Exposed town vs control town	Population. Exposed ( $n=23$ ), control ( $n=28$ )	PCBs, PBDEs, PBBs, DP, HCB, $\beta$ HCH, p,p'-DDE, lead	Plasma PCB total 2 times higher than control group. Link between plasma PCB levels and increased reactive oxygen species (ROS) levels.
Lin X et al. (26)	Guiyu, China	Exposed town vs control town	Preschool children (aged 2–7 years). Exposed ( $n=157$ ), control ( $n=127$ )	Lead, arsenic, mercury, chromium, cadmium, manganese, nickel, copper, zinc, selenium	Lead, cadmium, copper, zinc, nickel and manganese linked to imbalance of antibody titres.
Lin Y et al. (27)	Guiyu, China	Exposed town vs control town	Children (aged 2–7 years). Exposed ( $n=263$ ), control ( $n=115$ )	Lead	Lead associated with suppressed immune response in children.
Xu X et al. (28)	Guiyu, China	Exposed town vs control town	Children (aged 3–7 years). Exposed ( $n=301$ ), control ( $n=289$ )	Lead	Lead associated with reduced hepatitis B surface antibody (HBsAb) response.
Zhang Y et al. (29)	Guiyu, China	Exposed town vs control town	Children. Exposed ( $n=285$ ), control ( $n=126$ )	Lead	Lead negatively correlated with natural killer cell activities.
Zhang Y et al. (30)	Guiyu, China	Exposed town vs control town	Preschool children (aged 3–7 years). Exposed ( $n=153$ ), control ( $n=141$ )	Lead, cadmium	Lead and cadmium linked to alteration of number and percentage of several innate immune cells.
<b>Thyroid and endocrine system function</b>					
Eguchi A et al. (31)	Hung Yen province, Viet Nam	Exposed town vs control town	Informal workers. Exposed ( $n=77$ ), control ( $n=34$ )	PCBs, OH-PCBs, PBDEs, MeOPBDEs, OHPBDEs, BPhs	PCB and OH-PCB correlated with serum thyroid hormone (TH) levels in females.
Eguchi A et al. (32)	Northern Viet Nam	Exposed town vs control town	Population. Exposed ( $n=83$ ), control ( $n=48$ )	Perchlorate, thiocyanate	No significant difference found in thiocyanate (SCN <sup>-</sup> ). No correlation with TH levels.

**Table 2.1**  
**Literature review: health effects of exposure to e-waste, by health outcome, continued**

Author	Exposure location	Exposure setting	Exposed population	Primary toxicant	Health outcome
Lv QX et al. (33)	Wenling, China	Exposed town vs control town	Pregnant women. Exposed for over 5 years ( $n=64$ ), exposed for under 2 years and not employed in e-waste recycling ( $n=10$ )	PCBs, PBDEs	Serum PCBs negatively correlated with thyroid-stimulating hormone (TSH) levels in women of reproductive age.
Xu P et al. (34)	Zhejiang province, China	Exposed town vs control town	Population. Exposed ( $n=40$ ), control ( $n=15$ )	PCBs	Increased body burden of PCBs and specific PBDE congeners. PCBs negatively correlated with free thyroxine (FT4), free triiodothyronine (FT3), monocytes, lymphocytes. PBDEs positively correlated with white blood cells, haemoglobin, platelets.
Xu P et al. (35)	Zhejiang province, China	Exposed town vs control town	Children (aged 8 years). Exposed ( $n=21$ ), control ( $n=24$ )	PCBs, PBDEs, PCDDs, PCDFs	Serum PCDDs and PCDFs not significant. PBDEs positively correlated with adrenocorticotrophic hormone (ACTH).
<b>Lung function, respiratory function and asthma</b>					
Zeng X et al. (36)	Guiyu, China	Exposed town vs control towns	School children (aged 5–7 years). Exposed ( $n=100$ ), control ( $n=106$ )	Lead	Birth weight and chest circumference correlated with lung function levels in preschool children.
Zeng X et al. (37)	Guiyu, China	Exposed town vs control towns	School children (aged 5–7 years). Exposed ( $n=100$ ), control ( $n=106$ )	Lead, cadmium	Risk of increased levels of lead, cadmium, platelets and decreased levels of haemoglobin and lung function. The same study population as Zeng et al. (36).
Zeng X et al. (38)	Guiyu, China	Exposed town vs control town	Children (aged 3–8 years). Exposed ( $n=300$ ), control ( $n=170$ )	Lead, cadmium, chromium, manganese in $PM_{2.5}$ and blood	Blood lead and cadmium associated with prevalence of cough and asthma.
<b>Airway antimicrobial activity</b>					
Zhang S et al. (39)	Guiyu, China	Exposed town vs control town	Children (aged 2–7 years). Exposed ( $n=110$ ), control ( $n=112$ )	$PM_{2.5}$	$PM_{2.5}$ may reduce airway antimicrobial activity and downregulate salivary agglutinin (SAG) levels.
<b>Cardiovascular risk factors</b>					
Lu X et al. (40)	Guiyu, China	Exposed town vs control town	Children (aged 3–7 years). Exposed ( $n=337$ ), control ( $n=253$ )	Lead	Lead associated with higher prevalence of vascular inflammation and lipid disorder.
Zheng X et al. (41)	Guiyu, China	Exposed town vs control town	Children (aged 3–7 years). Exposed ( $n=105$ ), control ( $n=98$ )	Lead, PAHs	Lead and PAHs linked to vascular endothelial inflammation.



**Table 2.1****Literature review: health effects of exposure to e-waste, by health outcome, continued**

Author	Exposure location	Exposure setting	Exposed population	Primary toxicant	Health outcome
Cong X et al. (42)	Guiyu, China	Exposed town vs control town	Preschool children. Exposed ( $n=228$ ), children native to reference area ( $n=104$ ), non-native children living in reference area for > 1 year ( $n=91$ )	PM <sub>2.5</sub> , PM <sub>10</sub> , sulfur dioxide, nitrogen dioxide, carbon monoxide	Air pollution exposure linked to increase in heart rate and plasma norepinephrine.
<b>Hearing loss</b>					
Liu Y et al. (43)	Guiyu, China	Exposed town vs control town	Children (aged 3–7 years). Exposed ( $n=146$ ), control ( $n=88$ )	Lead, cadmium	Childhood lead exposure may be a risk factor in hearing loss in children.
<b>Olfactory memory</b>					
Zhang B et al. (44)	Guiyu, China	Exposed town vs control town	Children (aged 6 years). Exposed ( $n=61$ ), control ( $n=57$ )	Lead	Lead linked to increase in serum brain-derived neurotrophic factor (BDNF) and decrease in child olfactory memory.
<b>Liver function</b>					
Chen Y et al. (45)	Guiyu, China	Exposed town vs control town	Hospitalized adults. Exposed ( $n=158$ ), control ( $n=109$ )	Lead, cadmium	Lead and cadmium associated with elevated haematological and hepatic parameters in both control and exposed groups.
<b>Impaired blood coagulation</b>					
Zeng Z et al. (46)	Guiyu, China	Exposed town vs control town	Children. Exposed ( $n=331$ ), control ( $n=135$ )	Lead	Lead associated with increased coagulation process and activation of platelets.
<b>Fasting blood glucose levels</b>					
Song S et al. (47)	Qingyuan, China	Exposed towns vs control town	Population. Adults (aged 56–93 years). Exposed ( $n=119$ ), control ( $n=16$ )	Bisphenols (BPs)	Bisphenols A and AF (BPA and BPAF) may be associated with abnormal fasting blood glucose levels.
<b>Male reproductive disorders, genital diseases and sperm quality</b>					
Xu X et al. (48)	Guiyu, China	Exposed town vs control urban area	Hospital outpatients. Exposed ( $n=473$ 938), control ( $n=668$ 764)	Not assessed	Higher morbidity of male genital disease is of concern and male reproductive health may be threatened by e-waste environmental pollution.
Yu YJ et al. (49)	Guiyu, China	Exposed towns vs control town	Males (aged 18–50 years). Exposed ( $n=32$ ), control ( $n=25$ )	PBDEs	PBDEs may have adverse effects on human semen quality.
<b>Kidney injury markers</b>					
Xu P et al. (34)	Zhejiang province, China	Exposed town vs control town	Population (aged 15–65 years). Exposed ( $n=40$ ), control ( $n=15$ )	PCBs, PBDEs	Increased body burdens of PCBs and specific PBDE congeners may contribute to kidney injury markers.

**Table 2.1**  
**Literature review: health effects of exposure to e-waste, by health outcome, continued**

Author	Exposure location	Exposure setting	Exposed population	Primary toxicant	Health outcome
<b>DNA damage</b>					
Ni W et al. (50)	Guiyu, China	Maternal or paternal recycling activity vs control town	Pregnant women, newborn infants. Exposed ( $n=126$ ), control ( $n=75$ )	Lead, cadmium, chromium, nickel	Cadmium, chromium and nickel associated with increased oxidative DNA damage.
He X et al. (51)	China	Exposed town vs control town	Population. Exposed ( $n=23$ ), control ( $n=25$ )	PCBs, BDEs, DP, HCB, HCH, DDE	Significant associations between POP exposure and DNA lesions and dysregulation of DNA damage repair mechanisms.
Xu X et al. (52)	Guiyu, China	Exposed town	Children (aged 3–6 years). ( $n=118$ )	Lead, cadmium, mercury	Lead and mercury may increase levels of DNA damage, but no effect on DNA repair capacity. No association with cadmium.
<b>Gene expression</b>					
Li K et al. (53)	Jinghai, China	Exposed town vs control town	Adults employed primarily in non-e-waste sectors. Living within 5 km of ewaste facilities ( $n=30$ ) and 40 km from e-waste facilities ( $n=28$ )	Calcium, copper, iron, lead, magnesium, selenium, zinc, PCBs, PBDEs, DP, BB-153	Residing in close proximity to e-waste disposal facilities ( $\leq 5$ km) may be associated with the accumulation of potentially harmful inorganic and organic compounds and gender-preferential genetic aberrations.
<b>Oxidative stress</b>					
Zhang T et al. (54)	Qingyuan, China	Exposed town vs control urban and rural areas	Population (aged 0.4–87 years). Exposed ( $n=116$ ), control ( $n=42$ )	Bisphenols (BPs)	Significant positive correlations between urinary concentrations of 8-OHdG and BPA/BPS in exposed and control areas. BPA and bisphenol S (BPS) exposure are associated with oxidative stress.
Lu SY et al. (55)	Qingyuan, China	Exposed town vs control urban and rural areas	Population (aged 0.4–87 years). Exposed ( $n=175$ ), control ( $n=46$ )	Organophosphate flame retardants and plasticizers	Association between organophosphate (OP) exposure and oxidative stress in humans.
Lu SY et al. (56)	Qingyuan, China	Exposed towns vs control urban area	Population. Exposed ( $n=130$ ), control ( $n=46$ )	PAHs	PAH exposure may be associated with oxidative stress.
Zhou X et al. (57)	Guiyu, China	E-waste recycling workers and residents of areas with e-waste recycling vs control town	Pregnant women and neonates. Exposed pregnant women ( $n=46$ ), control ( $n=44$ )	Not assessed	Prenatal exposure to e-waste is linked to elevated female sex hormone levels and oxidative stress.
Li R et al. (58)	China	Exposed town vs control town	Adults. Exposed ( $n=23$ ), control ( $n=28$ )	PCBs, PBDEs, PBBs, DP, HCB, $\beta$ HCH, p,p'-DDE, lead	Link between exposure to air pollutants and elevated oxidative stress and altered immune function.

$\beta$ -HCH:  $\beta$ -hexachlorocyclohexane; BB-153: 2,2',4,4',5,5'-hexabromobiphenyl; BDE: brominated diphenyl ether; BPh: bromophenol; DDE: dichlorodiphenyldichloroethylene; DP: dechlorane plus; HCB: hexachlorobenzene; HCH: hexachlorocyclohexane; Hct: haematocrit; Hgb: haemoglobin; MCH: mean corpuscular haemoglobin; MCHC: mean corpuscular haemoglobin concentration; MCV: mean corpuscular volume; MeO-PBDE: methoxylated polybrominated diphenyl ether; OH-PBDE: hydroxylated polybrominated diphenyl ether; OH-PCB: hydroxylated polychlorinated biphenyl.

The COVID-19 pandemic, which began after the literature review for this report was completed, has heightened awareness of infectious disease risks to which informal waste workers are exposed as a result of the poor safety and sanitation standards that they face in their worksites and workplaces. At the time of the literature review, a small number of studies were identified that explore the role that exposure to e-waste plays in suppressing immune responses in children. Due to the above reason, this review does not specifically address the risks that COVID-19 poses to informal waste workers. However, the COVID-19 pandemic has highlighted the need for further research exploring infectious disease risks faced by informal waste workers and their communities.

The majority of studies measuring both exposure to e-waste and health outcomes have been carried out in China. A small number have been conducted in Chile, Ghana, Thailand and Viet Nam. What follows is a summary of studies of health impacts

by disease risk or condition, including key findings from the original 2013 systematic review and an abridged review conducted for this report.

## 2.1 Injuries and short-term effects

The manual dismantling or repair of e-waste can cause injury, especially without properly designed and maintained protective equipment (7, 59). Workers risk burns, cuts, sprains, puncture wounds, and fractures, and many do not pursue treatment for their injuries at a hospital or health clinic (7). Children living in e-waste communities are also at risk of injuries from working or playing with dismantled equipment.

High rates of self-reported insomnia, weakness, muscle atrophy, headaches, cough, chest pain and dizziness have also been found among workers in Thailand and Ghana (5, 6).



## 2.2 Adverse neonatal outcomes

Exposure to hazardous chemicals in e-waste recycling during pregnancy has been associated with adverse neonatal outcomes in studies in China. These include increased rates of stillbirth, premature birth, shortened gestational age, lower birth weight, shorter birth length, reduced body mass index, lower Ponderal index (a measure of leanness), and smaller head circumference. Poorer Apgar scores (a test commonly used to measure the physical health of newborns) have been found in infants of mothers exposed to informal e-waste recycling (8–12, 60–66). These studies investigated a range of individual chemical exposures, including PAHs and hydroxylated PAHs (OH-PAH), PBDEs, PCBs, perfluorooctanoic acid (PFOA), lead, cadmium, nickel, and chromium.

Studies conducted in European and North American countries of exposure to air pollution and PAHs in non-e-waste settings supported the findings from investigations in China. Exposure to particulate matters significantly increases risk of preterm birth (67). Prenatal exposure to PAHs was associated with high risk of lower birth weight and birth length, smaller head circumference (68), premature delivery and intrauterine growth retardation (69).

Studies of metals have been less consistent, probably because people at e-waste sites are never exposed only to one substance, and it is therefore difficult to distinguish the specific effects of one chemical. In one study, cadmium was inversely associated with birth weight and length, and in another it was found to only impact birth outcomes in female infants (8, 10). Another study found no association between cadmium exposure and birth outcomes (60). Increased placental concentrations of nickel may be correlated with gestational age (60).

## 2.3 Growth

Studies of exposure to e-waste and growth (for example, height and weight) in children have reported mixed results (14, 16, 70–72). Higher exposure to manganese, nickel (72), lead (14, 16) and PAHs (14) from informal e-waste recycling have been associated with reduced growth in a small number of studies. One study reported an association between exposure to chromium in e-waste and increased height and weight in children, especially in boys (71).

## 2.4 Neurodevelopment, learning and behavioural outcomes

E-waste contains several recognized neurotoxicants. Lead, mercury, cadmium, PAHs, PCBs, PCDDs, PCDFs and PBDEs are known or suspected to impact neurodevelopment and cognitive function (1, 73, 74). Early life exposure to air pollution is also known to cause a reduction in cognitive abilities (75).

Exposure to lead from e-waste recycling activities has been associated with significantly reduced neonatal behavioural neurological assessment scores (76), increased rates of attention deficit/hyperactivity disorder (ADHD) (20, 21), behavioural problems (20), changes in child temperament (77), sensory integration difficulties (17), and reduced cognitive and language scores (18, 19). One study did not find any significant differences in intelligence quotient (IQ) between children exposed to e-waste and children not exposed to e-waste (78). However, for all children included in the study, higher blood lead levels were associated with reduced IQ (78). Exposure to cadmium and manganese was also correlated with behavioural problems in one study of kindergarten children exposed to mixtures of metals from e-waste (20). Some of these results should be interpreted with caution due to limitations in study design,

including the unclear use of control groups and the pooling of samples from exposed and control groups.

There is, however, a large body of research on the effect of lead exposure, even at low levels, on a wide range of children's neurocognitive, behavioural and learning outcomes (79–82). Changes in attention, reduced cognition and behavioural scores, impaired visual motor and reasoning skills, impaired social behaviour, and impaired reading ability have all been associated with lead exposure, and may continue into adulthood (83–87).

Although their neurodevelopmental effects have not been studied as comprehensively at e-waste recycling sites, mercury, PAHs, PCBs, PCDDs, PCDFs and PBDEs are known to impact neurodevelopment and cognitive function (1, 73, 74). Exposure to methylmercury, particularly during pregnancy and early childhood, is associated with impaired cognition, language, memory, motor

function, and attention (73, 88), while exposure to PCBs is associated with changes in cognition, visual-spatial function, attention, memory, executive function, motor function, and behaviour in children (73, 89, 90). Exposure to cadmium, PBDEs, PCDDs, PCDFs and PAHs has also been associated with impaired cognition (73, 74). Whether cadmium exposure is associated with neurobehavioural effects is less certain (73).

## 2.5 Immune system function

A small number of studies have reported that exposure to e-waste plays a role in suppressing immune responses in children. These studies have investigated different measures of immunity, including red blood cell immunity, natural killer cells, and innate and adaptive immune response, but have consistently found associations between increased exposure to lead from e-waste and decreased immune function (22–24, 29, 30).



One study suggests that exposure to cadmium from e-waste recycling activities may impair the innate and adaptive immune systems of children (30).

Three studies have suggested that exposure to e-waste may impede the development of immunity to infectious diseases after vaccination (26, 27, 65). In these studies, high levels of blood lead, copper and zinc were correlated with reduced antibody titres – a biomarker used to assess immunity from key infectious diseases following vaccination (26, 27, 65). Specifically, antibody titres for measles, mumps, rubella, hepatitis B, diphtheria, pertussis, tetanus, Japanese encephalitis and polio were reduced in children previously exposed to high levels of the heavy metals. In some cases, antibody titres were below levels needed for protection from infection (27, 65). However, it is unlikely that the reduced immunity following immunization was due to the metal exposure, because most metals stimulate the immune

system, promoting allergy and autoimmunity (91). These studies did not measure exposure to PCBs, which are found in e-waste, and have been associated with reduced antibody response to vaccination in non-e-waste-exposed populations (92–94). It is possible that the reduced response to immunization was due to concurrent PCB exposure.

## 2.6 Thyroid function

Thyroid hormones play a critical role in early brain development, particularly during early pregnancy before a fetus's own thyroid gland is functioning. Thyroid hormone levels during pregnancy below or above the normal range can adversely impact neurodevelopment (95, 96). Maternal hypothyroidism during pregnancy has been associated with structural changes in the brain of children and intellectual disability (31, 97).



There is evidence suggesting an association between exposure to e-waste and thyroid function, but the findings of studies in exposed populations have not been consistent.

Increased levels of PBDEs, PCDDs, PCDFs, OH-PCB, BDE-205 and dioxins have been associated with changes in thyroid hormone levels in many publications (31, 33, 34, 98–100), but the direction of changes is inconsistent.

In some studies in China, thyroid-stimulating hormone was elevated in some populations exposed to e-waste, lower in some other studies, and yet others reported no statistically significant difference (32, 34, 35, 99–102). Similar inconsistencies were reported in findings on the thyroid hormones tests for thyroxine (T4), free thyroxine (fT4), total thyroxine (TT4) and total triiodothyronine (TT3) (35, 99, 102). It is likely that the explanation for the inconsistent reports is the fact that each of these classes of chemicals is composed of many different congeners, depending on how many chlorines or bromines are found on the rings and where they are located. Not all congeners of PBDEs and PCBs have the same action (103), and it is likely that some congeners stimulate thyroid function, while others depress it. These differing and even opposite effects of different PCB congeners have been seen in other health outcomes (104). In addition, children or pregnant women may be exposed to many other chemicals that can vary among e-waste sites, and the additive, synergistic and antagonistic interactions of chemical mixtures in e-waste are not fully known.

## 2.7 Lung function, respiratory symptoms and asthma

The respiratory system is particularly vulnerable to damage from environmental pollutants during gestation, childhood and adolescence (105). Compared to adults, children have narrower airways, so even low levels of air pollution exposure are more

likely to impact lung function (72, 106). Some groups, such as asthmatics, have reduced antioxidant defences in their lung lining fluid, and are more sensitive to air pollution (107). Fine particulate air pollution is known to increase rates of post-neonatal mortality (108) and asthma (109).

Exposure to e-waste recycling activities has been associated with reduced lung function of children aged 5–9 years, although there was no significant association found in children aged 10–13 years (36, 37, 72). This is generally consistent with studies of air pollution exposure.

Living in an e-waste recycling town or near an e-waste recycling site, and being in contact with e-waste, have also been associated with childhood respiratory symptoms (38). Exposure to chromium from e-waste may be associated with cough, and manganese may be associated with wheeze in preschool children (38). Blood lead levels of > 5 micrograms per decilitre ( $\mu\text{g}/\text{dL}$ ) and living near an e-waste recycling site were associated with increased risk of asthma in the same study (38).

Exposure to fine particulate matter ( $\text{PM}_{2.5}$ ) from e-waste recycling may also weaken airway antimicrobial activity, increasing vulnerability to respiratory infections among preschool children (39).

Some pollutants found in e-waste or produced by the combustion of e-waste are also found in indoor and ambient air pollution from other sources. Exposure to air pollution in early life has been associated with a range of respiratory effects, including acute lower respiratory infections and deficits in lung function growth in children, asthma development and asthma exacerbation (110). Outdoor air pollution and particulate matter from outdoor air pollution have been classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC) (111, 112).

## 2.8 Cardiovascular health

Cardiovascular regulatory changes during early life may impact cardiovascular health in adulthood, and the development of cardiovascular diseases such as heart attack and stroke (42). Exposure to both PAHs and lead has been individually associated with the development of cardiovascular disease in adults (113–115).

In one study of preschool children, air pollution from e-waste recycling activities was associated with increased heart rate and norepinephrine, biomarkers of sympatho-adrenomedullary function (42). Other studies have found associations between lead exposure from e-waste recycling and abnormal measures of cardiovascular physiology, vascular inflammation and abnormal blood pressure (40, 41). Exposure to PAHs from e-waste sites has also been associated with inflammation of the cells that line the surface of blood vessels (vascular endothelial inflammation) in children (41).

## 2.9 Other health outcomes

Other studies have reported possible associations between exposure to e-waste and hearing loss (43), olfactory memory (44), and rapid onset of blood coagulation (46) in children.

Associations between e-waste exposure and kidney injury markers (34), liver function (45), male reproductive and genital disorders (48), sperm quality (49), and fasting blood glucose levels (47) have been found in a small number of studies of adults. Although too few studies have been published to draw conclusions on these individual outcomes, they suggest that e-waste exposure may impact numerous body systems.

Exposure to several of the toxicants found at e-waste sites is known to increase the risk of developing diseases that only appear

later in life. Of particular concern are chronic diseases including cancer, type 2 diabetes, hypertension, cardiovascular disease, obesity, metabolic syndrome and osteoporosis (116). Children living, working and playing near and at e-waste sites have not yet been observed for a sufficient time to determine these outcomes, but the evidence from other studies indicates that this is an important concern.

## 2.10 Mechanisms of action

### 2.10.1 DNA damage

There is a growing body of research suggesting that DNA damage and its unsuccessful repair plays a role in the development of cancerous tumours (51, 117). The frequency of micronuclei in human cells is used to measure cell death, cell proliferation, and chromosome changes, and can be used as a reliable indicator of DNA damage (118, 119).

In regard to DNA impacts from e-waste exposure, although studies so far have generally been small and have used different methods to measure DNA damage, higher levels of DNA damage in exposed populations have consistently been found.

Several studies have reported increased micronuclei frequencies in adults exposed to informal e-waste recycling (53, 111, 118, 119). In one study, increased blood lead levels were associated with increased micronuclei frequency (118). These adults had been living in e-waste recycling areas for a relatively short period of time. Two other studies found associations between chromium, cadmium and nickel in umbilical cord blood and DNA damage in newborns (50, 117). Oxidative stress is an important potential mechanism for DNA damage in children exposed to heavy metals via e-waste (52).

Cadmium may be associated with shortened placental telomere length, which is involved



in ageing and cancer development (13). One study also reported higher rates of chromosomal aberration in adults exposed to e-waste recycling, with women more affected than men (120).

### 2.10.2 Gene expression

Many of the biological effects of e-waste chemicals are mediated by gene induction via activation of nuclear receptors (121). Nuclear receptors are found in the cytoplasm of cells, and agonists are lipophilic substances that cross the cell membrane and bind to the receptor; the complex then migrates to the nucleus, binds to DNA and induces genes to either upregulate (increase production of their protein) or downregulate (reduce production of it). Most hormone receptors, including estrogen, androgen and thyroid receptors, are nuclear receptors. There are others, such as the aryl hydrocarbon receptor (AhR), often called the dioxin receptor, which responds to a variety of xenobiotics and PAHs. Other important nuclear receptors include the constitutive androstane receptor (CAR), pregnane-X receptor (PXR), retinoid-X receptor (RXR), retinoic acid receptor (RAR) and peroxisome proliferator-activated receptor (PPAR)  $\alpha$  and  $\gamma$ . Each of these is a distinct nuclear receptor, and activation induces a different pattern of genes, often several hundred different genes. For example, PPAR  $\gamma$  regulates activities of insulin, glucocorticoids and immune function, and activity is altered by perfluorinated compounds, phthalates and bisphenol A (122, 123). Other nuclear receptors alter other physiological functions, and most are altered by one or more of the contaminants found at e-waste sites. Epigenetic changes in DNA methylation will also alter the patterns of gene induction (124).

Endocrine disruption is the term used for actions of xenobiotics that alter sex hormone or thyroid function, and most but not all of these actions are mediated through these nuclear receptor pathways. These actions are then reflected in changes in gene expression.

There are several important conclusions that follow from these patterns of gene induction. Because most nuclear receptors regulate many different genes, a chemical that perturbs that action can alter many different physiological functions and diseases. The second critical conclusion is that there is no threshold for effect, and one would expect to observe changes in rates of several different diseases. While most studies of chemical actions at the level of nuclear receptors have been of organic chemicals, it is likely that several metals that are associated with a variety of different diseases, such as lead and arsenic, also act at least in part by gene induction (123, 125).

There has been limited study of gene expression at e-waste sites. Metallothionein binds to some heavy metals, and plays a role in their storage, transport and detoxification, as well as in the growth and differentiation of cells (126). Increased placental and cord blood cadmium levels and increased expression of placental metallothionein were found in one study of neonates exposed to e-waste pollutants in Guiyu, China (126). A second study also found increased placental metallothionein expression, lower S100 calcium-binding protein P (S100P) and mRNA levels, and higher placental cadmium levels in Guiyu (127). Placental cadmium was correlated with increased metallothionein expression and decreased S100P protein expression.

MicroRNAs (miRNAs) are believed to play a role in the regulation of gene expression through each stage of spermatogenesis. One study has suggested a possible association between exposure to e-waste among male dumpsite workers in China and miRNA expression in their spermatozoa. The study reported 73 significantly upregulated and 109 downregulated miRNAs in spermatozoa of the exposed population (128). However, the RNA in each group was pooled, so it was not possible for the authors to make individual-level determinations.

### 2.10.3 Oxidative stress

Oxidative stress occurs when there is an imbalance in free radicals (reactive oxygen and nitrogen species) and antioxidant defences in the body (129). Oxidative stress plays a role in age-related chronic health conditions, including certain cancers, cardiovascular diseases, chronic obstructive pulmonary disease, chronic kidney disease and neurodegenerative diseases (129). Oxidative stress may also be involved in a wide range of childhood conditions (130).

There have been multiple studies on the impacts of e-waste exposure on oxidative stress. Elevated oxidative stress has been found in infants, workers, and adults living in e-waste recycling areas (54–57). Exposure to organophosphate flame retardants, plasticizers, PAHs, and bisphenols (BPA, BPS) has been associated with oxidative stress in populations exposed to e-waste (54–56).

## 2.11 Evidence about health impacts of exposure to specific chemicals found in e-waste

Despite the still-developing evidence on e-waste exposure, the evidence about the health impacts of individual chemicals frequently found in e-waste is well established, in terms of the harms caused to multiple body systems. Studies on toxic chemicals and metals in other contexts have continued to highlight new and known health effects associated with these toxicants (131–133). Many of these toxicants are also commonly found in e-waste. Table 2.2 lists some of the chemicals that are commonly found in e-waste, and which are already known or suspected to cause human health effects. As already noted, exposures of pregnant women and young children are especially significant. Certain exposures not only impact children’s immediate health and development but may also lead to the development of chronic health conditions in adulthood.

**Table 2.2**  
**Suspected human health effects of individual chemicals found in e-waste**

Health effects	Chemical component of e-waste suspected to cause human health effects (1)
Carcinogenic (cancer causing)	PCBs, dioxins, PAHs, PFOA (134), cadmium, arsenic, beryllium, chromium
Endocrine disruption	PBDEs, PCBs, dioxins, manganese, phthalates (135), bisphenols (135)
Fetal growth and development (low birth weight, low head circumference, intrauterine growth restriction)	PBDEs (9), PCBs, dioxins, PFAS, PAHs, lead (16, 65, 136), cadmium, arsenic, chromium (15)
Neurodevelopment and cognitive function (IQ deficits) (72)	PBDEs, PCBs, PAHs, lead, mercury, cadmium, manganese (137)
Behavioural effects (shortened attention span, reduced ability to deal with frustration, hyperactivity, antisocial behaviour, depression)	Lead, PCBs, dioxins (3), PAHs (3)
Reproductive effects	PBDEs, PCBs, dioxins, PFAS, lead, chromium, mercury, phthalates (135), bisphenols (135)
Metabolic diseases	PBDEs, dioxins
Bone damage	Cadmium
Liver damage	Nickel, iron, cadmium
Lung damage	PAHs, cadmium, arsenic, lithium
Kidney damage	Lead, cadmium, mercury
Cardiovascular	Dioxins, mercury, arsenic
Immune system suppression	PCBs (3, 93, 94), dioxins (3)
Immune system stimulation, promoting allergy and autoimmunity	Lead (28), nickel (26), mercury, chromium, gold (91)

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**3.  
E-waste and  
health action  
and policy  
agenda**



## E-waste and health action and policy agenda

Greater awareness about the health risks of e-waste for children, pregnant and lactating women, and other vulnerable groups should drive policies to reduce health risks in the labour market as well as throughout the entire life cycle of electronic products.

Key overarching goals should include:

- ensuring health and safety of e-waste workers, their families and communities in systems that train and protect workers and monitor exposures and health outcomes, with children's protection of a high priority;
- sound environmental health practices for disposal, recapture and reuse of materials;
- shifting to a circular economy through manufacture of more durable electronic and electrical equipment, using safer and less toxic materials;
- sustainable consumption leading to reduction of e-waste;
- health-aware and environmentally conscious management of e-waste throughout the life cycle, with reference to the Basel Convention, appropriate regional conventions and Sustainable Development Goal (SDG) target 11.6 on waste management;
- decent work for e-waste workers across the value chain (collection, processing or recycling, and resale), including the incorporation of informal workers in the formal economy and the elimination of hazardous child labour.

This chapter addresses some of the actions the health sector can take to achieve those aims, including through:

- advocating global and national policy agendas;
- assessing e-waste trends and children's health exposure;
- guiding risk reduction in workplaces, communities and health facilities;
- capacity-building for exposure reduction at local level;
- promoting and participating in action research.

Addressing e-waste appropriately can support the global transition to a more circular economy, and help foster safer workplaces and communities where the negative health impacts of e-waste exposure on children and other vulnerable groups are reduced or eliminated (Box 3.1).



**Box 3.1****Waste picking cooperative in Brazil promote gender balance and safety in e-waste recovery**

Coopermiti is a skilled cooperative that works with e-waste in São Paulo, Brazil. Created in 2010, with 30 members, 14 of whom are women, the cooperative has since collected over 2500 tonnes of discarded electrical and electronic objects. Coopermiti collects e-waste on demand and by voluntary drop-off, from households and the service, trade and industry sectors. All workers follow occupational safety and health regulations and standards to avoid environmental and health risks. Coopermiti is certified under international standards that specify requirements for quality environmental management systems (1). Implementing reverse logistics with recycling cooperatives opens new opportunities for income generation (particularly for youths and women), social inclusion, gender equity, decreased occupational health risks, education and skill development. Waste picker cooperatives contribute to the reduction of inappropriate disposal of e-waste and help to avoid environmental contamination, a significant problem in low- and middle-income countries. Yet, waste pickers still face persistent challenges related to prejudice and stigma, and they are often not recognized for the valuable work they do. Public policies are needed to legitimize the work of organized waste pickers and to facilitate their integration into organized resource recovery and promotion of gender equity and workplace safety (2, 3).



### 3.1 Global, regional and national policy agendas: acting together

With lower labour costs and fewer environmental and occupation health and safety protections, e-waste processing in low-income economies is significantly cheaper than state-of-the-art processing in high-income countries (4, 5).

Despite international efforts to reduce the shipment of e-waste to low-income and emerging economies, illegal e-waste shipments continue from high-income to low- and middle-income countries, even as local generation increases (6–9). Second-hand electronics and computer parts are frequently shipped legally as second-hand

goods for “resale,” but can later wind up in e-waste dumpsites (6).

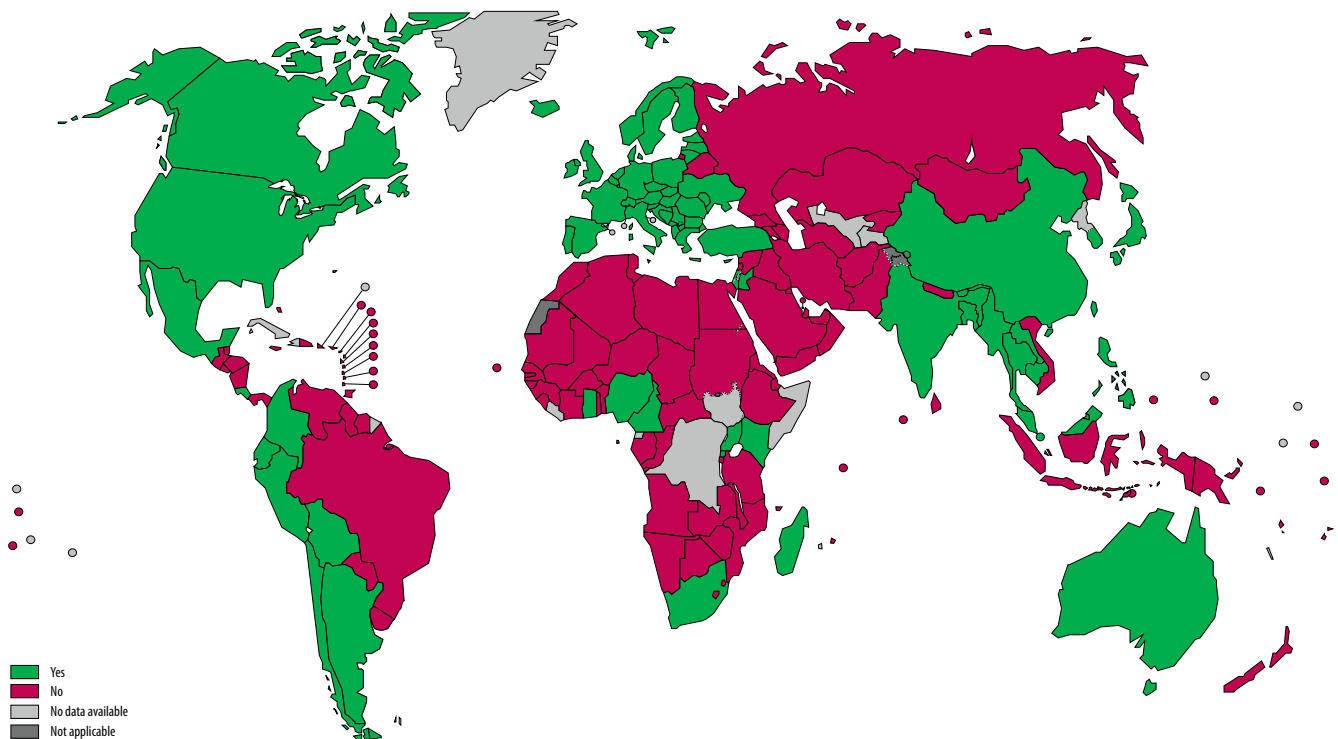
Additionally, low- and middle-income countries are increasingly producing local e-waste. This, combined with internationally imported e-waste, adds to the waste burden in countries where waste management needs to be strengthened, and where capacities and resources to safely dispose of hazardous waste are limited. Several regional approaches address multiple concerns around locally produced e-waste and the import of foreign e-waste. The Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa (1998) is a treaty of African countries that arose in response to Article 11 of the Basel Convention encouraging party countries to enter into regional agreements on hazardous waste

to help achieve the objectives of the Convention. The Bamako Convention aims to prohibit the import of any hazardous wastes, including radioactive waste, into African countries for any reason (10). The East African Communications Organisation has also produced a Regional E-waste Strategy aiming to improve management strategies in east African countries (11). Similarly, the Waigani Convention bans the import of hazardous wastes into Pacific Island countries but is also used as the mechanism to provide regional assistance in the form of technical capacity and infrastructure to countries that need and request it (12, 13).

For low- and middle-income countries, e-waste shipments may in fact represent a vital source of low-cost electronic equipment and parts, and at the same time e-waste recycling and related activities are often a critical source of income for many

households (14–18). In West Africa, for instance, workers can make significantly more money in e-waste management than in some other industries and have reported earning between US\$ 16 and US\$ 52 per workday (17). In Ghana alone, as many as 121 800 to 201 600 people depend fully or partially on informal e-waste recycling, collection or repairs for their households' economic livelihood (19).

Currently, 71% of the global population live in a country with some form of e-waste management legislation (20) (Figure 3.1). Where it does exist, such legislation is often patchy or incomplete, as well as lacking in effective enforcement measures (21). Against this landscape, the health sector must advocate the systematic inclusion of health considerations into existing and new e-waste policies, particularly with regard to the following.



Source: : Global E-waste Monitor (20).

**Fig. 3.1**  
Countries with national e-waste legislation, policy or regulation in place, 2019

- **Adoption and enforcement of the high-level political agreements related to e-waste.** Most countries are parties to the major United Nations conventions related to the sound management of waste from cradle to grave, including the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and the Stockholm Convention on Persistent Organic Pollutants (22, 23). In 2019, the Ban Amendment to the Basel Convention entered into force. It prohibits the movement of hazardous wastes from countries of the Organisation for Economic Co-operation and Development (OECD), the European Commission countries and Liechtenstein to other States that are party to the Basel Convention. The Minamata Convention on Mercury is also relevant (24). Additionally, there are a number of regional initiatives and conventions that aim to curb the import of e-waste, including the Waigani Convention (12) for the South Pacific region and the Bamako Convention for the African nations, which prohibits import of hazardous waste into African countries (10). Also of relevance is the ILO Worst Forms of Child Labour Convention, 1999 (No. 182) (25).
- **Incorporation of health protection measures.** Strong health protection measures need to be incorporated into new electronics manufacturing and waste management initiatives, as well as into assessment of environmental contamination of agriculture, water, and residential neighbourhoods. Systems to evaluate the harms and benefits to health of policy choices need to be embedded into policies and interventions from their inception (26).
- **Assessment of health co-benefits of addressing e-waste risks.** Policies to encourage safe and efficient recycling

also have the potential to reduce health care costs by preventing e-waste-related injuries and health conditions. Implementation of sound e-waste management solutions can thus be of triple benefit to health, the environment, and the waste management sector.

- **Development of health-relevant targets and action points for existing and future e-waste policies.** The protection of children's health – both present and future – should be a major policy driver (Box 3.2).
- **Monitoring and surveillance.** Better monitoring and surveillance is needed of toxic exposure in health and occupational health systems.
- **Consideration, with the labour sector, of more robust methods for national and global tracking.** Such tracking would provide labour market data on the numbers of informal e-waste workers exposed and at risk, particularly illegally employed child waste workers, through existing labour survey tools (27) (see Annex 2).

The Health in All Policies approach provides a useful policy strategy for multisectoral collaboration and working together to achieve mutually beneficial outcomes across relevant policy areas. Health in All Policies operates to ensure that policy-making is harmonized, that is, efforts do not undermine other priorities and conflicts of interest can be resolved in a timely and transparent manner. By incorporating the consideration of health impacts into the policy development processes of all sectors, a Health in All Policies approach can support governments to address the challenges of e-waste disposal and management in a systematic manner, recognizing the strong influence of other sectors' policies on health outcomes (Figure 3.2).

**Box 3.2****E-waste policy measures for health sector advocacy and engagement****Improved product design**

- Establish global policies and national regulations to phase out the use of the most hazardous components used in electronic and electrical equipment, and promote reduced-risk alternatives, taking into account the life cycle of substances and products.
- Advocate improved product design at manufacturer and consumer levels, focusing on maximum durability, reparability and reusability (28).

**Reduction of production of e-wastes**

- Raise awareness of and promote behavioural change among consumers (28).

**Safe collection and treatment of used equipment**

- Take greater responsibility for the safe treatment of e-waste, particularly in countries that export e-waste, among both national governments and corporate actors (29).
- Implement and enforce policies on extended producer responsibility to make manufacturers of electronic devices responsible for their disposal in developed and emerging economies, including through reuse and waste reduction policies and take-back programmes (28).
- Identify e-waste streams and strengthen collection and management of e-waste at the national level, supported by the development of local and regional recycling facilities.
- Support regulations to prevent discharge of toxic chemicals.
- Ensure national regulations are implemented and enforced and increase capacity for enforcement in countries where e-waste is treated informally.
- Enhance national consumer awareness of the damaging effects of informal e-waste recycling (29).

**Controlling transboundary movements and preventing and combating illegal traffic of e-waste**

- Support law enforcement and customs authorities to identify and address illegal transboundary movement of used and end-of-life products entering developing economies (22).

**Risk reduction in informal recycling communities**

- As a transitional approach, investigate manual dismantling of local e-waste in sites, neighbourhoods or regions of low-income and emerging economies, and shipment of critical fractions for high-tech processing in formal recycling facilities, facilitated by such frameworks as the Best-of-2-Worlds approach (30) and a broadly synergistic interaction approach (31).
- Eradicate child labour within e-waste recycling areas (25, 32).

**Decommissioning electronic medical devices**

- Ensure that guidelines and facilities are available for the proper management of decommissioned electronic medical devices in order to reduce waste and minimize the risk of harmful exposure of personnel, the public and the environment (33).

**Access to health care services**

- Ensure a well trained, motivated and supported health workforce that is able to provide quality health care for e-waste workers, their families and the communities that are exposed to the health risks of e-waste (29).
- Ensure adequate health care is available and affordable for workers and communities, as advocated by the Astana Declaration on Primary Health Care (34).

**Sustainable funding for action**

- Mobilize financial resources to support e-waste action, including programmes for monitoring and reducing health risks (21).



**Fig. 3.2**  
**Addressing risks of and opportunities for multisectoral action: what actors can do**

Networked responses, such as Health in All Policies, require the health sector to stretch beyond a core advocacy function and increasingly take on multiple roles, depending on the context – that of a leader, partner, negotiator, facilitator, broker or advocate for health. Through crossing policy boundaries, the policy dialogue on health can be strengthened and help to bridge gaps across policy domains, while gaining a deeper understanding of the perspectives of different stakeholders.

The health sector can lead by example by developing sound e-waste policies in

health facilities as part of broader initiatives to “green” the health sector by providing safely managed water, sanitation and hygienic facilities, and safe and reliable energy supplies. Health care facilities must address the safe management of their e-waste (26, 33). There are a number of World Health Assembly resolutions that address the links between health and environmentally sound waste management. Box 3.3 gives more details on these resolutions, while Box 3.4 presents information on policy efforts to reduce blood lead levels in children at e-waste sites in China.

### **Box 3.3** **World Health Assembly resolutions related to e-waste**

A number of World Health Assembly resolutions and decisions highlight the important role that the health sector can play in reducing toxicants produced during informal or unregulated e-waste recycling. These resolutions and decisions request that WHO and the health sector report on and implement actions related to toxic wastes and waste burning to protect health and the environment.

#### **Resolution WHA63.25: Improvement of health through safe and environmentally sound waste management**

The resolution urges that Member States undertake a health impact assessment as a key tool for assessing the health aspects of waste management as part of the process of ensuring safe and environmentally sound waste management. It also requests that WHO explore options to work more closely with a range of international organizations to strengthen and improve appropriate technical capacities at national, regional and international levels to ensure the safe and environmentally sound management of wastes (35).

#### **Resolution WHA68.8: Health and the environment: addressing the health impact of air pollution**

The resolution supports the strengthening of WHO and Member States to combat air pollution and protect health through measures such as air quality guidelines, monitoring systems, capacity-building, research and multisectoral action (36).

#### **Resolution WHA69.4 and decision WHA70(23): The role of the health sector in the Strategic Approach to International Chemicals Management towards the 2020 goal and beyond**

The resolution and decision underline the need to strengthen the health sector’s role in the sound management of chemicals at the national, regional and international levels in order to minimize the risk of adverse health impacts of chemicals throughout their life cycles (37).

#### **Decision WHA72(9): WHO global strategy on health, environment and climate change: the transformation needed to improve lives and well-being sustainably through healthy environments**

This decision aims to provide a vision and way forward on how the world and its health community need to respond to environmental health risks and challenges until 2030. The strategy aims to ensure safe, enabling and equitable environments for health by transforming our way of living, working, producing, consuming and governing (26).

**Box 3.4****Efforts to reduce blood lead levels in children at e-waste sites in China**

In the early 2000s, in response to reports of soaring blood lead levels in children, the Chinese Government introduced a number of new measures and policies that aimed to reduce human exposure to harmful toxicants released during informal e-waste recycling. The interventions, which were carried out at national and local government levels, were supported by the participation of researchers working on the ground at major e-waste sites, such as Guiyu and Taizhou. Activities to reduce children's blood lead levels in China included the organization of formal e-waste recycling workshops, and stricter regulations on the amount of e-waste imported into the country. At the local, community level, initiatives included educational sessions, posters and pamphlets explaining the dangers, and methods of preventing, lead poisoning, aimed at parents and children who live and work in e-waste management areas (38).



Research following these interventions has indicated decreasing trends of blood lead levels in children. A 2004 study of 165 kindergarten children in Guiyu found an average blood lead level of 15.3 micrograms per decilitre ( $\mu\text{g}/\text{dL}$ ), while research conducted in 2006 in the same kindergartens found that the average blood lead level of children had decreased somewhat to 13.7  $\mu\text{g}/\text{dL}$  (39, 40). More recent studies have suggested that blood lead levels of children in Guiyu continue to fall. Research undertaken in 2017 and 2018 found 332 and 357 children in the same area had median blood lead levels of 6.5  $\mu\text{g}/\text{dL}$  and 4.86  $\mu\text{g}/\text{dL}$ , respectively (41, 42). Additionally, epidemiological studies conducted in Guiyu have suggested that the proportion of blood lead levels in preschool children exceeding 5  $\mu\text{g}/\text{dL}$  is decreasing over time. Studies have found that the proportion of preschool children with blood lead levels exceeding 5  $\mu\text{g}/\text{dL}$  has fallen from 83% in 2014 (43) to 66% in 2016 (44) and to 43.8% in 2018 (45). These trends may be partly attributed to the implementation of national and local regulations changing the way e-waste is recycled in Guiyu. Future research, especially longitudinal studies with significant numbers of participants, needs to be undertaken to monitor the blood lead levels of children in Guiyu to confirm trends and contributing factors.

## 3.2 Improving surveillance and assessment of trends in e-waste exposure and health impacts

There are significant gaps in reliable data on the e-waste labour market and e-waste management (15, 46–48), particularly with regard to data on e-waste and health impacts. Collecting reliable data can improve the development and evaluation of policies, and support advocacy.

It is critical to work towards integrated surveillance and monitoring of environmental pollution from e-waste, levels of human exposure to its toxicants, associated body burden of those toxic exposures, and their health effects at the national, regional and international levels. To achieve this, a number of actions and measures can be undertaken.

- Improve national and regional capacities and international coordination for monitoring and surveillance.
- Work towards integrated health and environmental monitoring and surveillance systems (49).

**Box 3.5****Future directions for developing new indicators**

More research is needed to determine the most appropriate indicators and adapt them to national contexts. However, based on available strategies, some of the following approaches may be considered.

**Environmental monitoring of proxy indicators of exposure.** Considering the local availability of analytical techniques, some useful proxy indicators of exposure may include:

- levels of lead in soil, indoors (in residences without leaded paint) or in outdoor dust. Testing for lead and other metals is cost-effective, and handheld environmental monitoring devices are available;
- levels of POPs, PFOA, PBDE and dioxins in soil and water;
- levels of PAHs and PM<sub>2.5</sub> in air.

**Monitoring of the size of potentially exposed populations.** More accurate baseline data on numbers of men, women and children employed in the waste sector, formal and informal, would allow for deeper analysis of:

- women and adolescent girls of childbearing age (15–49 years) working in e-waste recycling in unregulated workplaces;
- children aged 0–18 years scavenging in waste dumps or living in homes where e-waste is dismantled, burned or processed.

**Biomedical monitoring of common indicators of chemical exposure.** While often too expensive or unfeasible in routine clinical practice, studies of biomarker levels in at-risk groups can be used to confirm population-level exposures and monitor trends over time (54):

- blood lead levels in children aged 0–6 years;
- mean annual exposure of children aged 0–4 years to atmospheric particulate pollution (55, 56);
- mean weekly PM exposure among workers inside workplaces using personal or portable air pollution monitors.

- Develop harmonized indicators (soil, air pollution, biomonitoring, health effects) for monitoring e-waste-related chemicals throughout their life cycles. The input of the health sector is critical to developing indicators and collecting and interpreting health statistics related to e-waste (50). Potential indicators are included in Box 3.5, but additional work is needed to determine the most appropriate indicators and adapt them to national contexts.
- Strengthen capacity of primary health systems and care providers to detect and diagnose toxic exposures to e-waste chemicals and heavy metals.
- Strengthen the capacity of national and local laboratories to detect toxic exposures in blood or other biological samples, and to monitor environmental contamination. This may require building the capacity

of laboratory facilities, establishing new laboratories, and training in analytical methods and quality control (51).

- Strengthen systems to document cases of hospital admissions and deaths suspected of being due to e-waste exposure (52).
- Build national capacities for the notification and recording of occupational diseases.
- Conduct further research into methods for measuring exposures to toxic e-waste, particularly in light of their varied materials and metal content (29).

The Global E-waste Statistics Partnership was developed in 2017 to improve the collection and interpretation of e-waste statistics (53). It supports countries to improve the collection and interpretation of e-waste statistics to inform policy-makers, industry, academia, media and the public.



Indicators for health risk assessment in e-waste sites have to be context specific; however, some general observations can be made for the following indicators.

**Environmental monitoring.** After a pathway of exposure assessment (under the definition of the Agency for Toxic Substances and Disease Registry), levels of chemicals of concern at the points of exposure have to be determined. Samples of air (PM<sub>2.5</sub>), surface soil, dust (indoor and outdoor), water or food items can be collected, prioritizing pathways where children can be most exposed to chemicals (bearing in mind the context-specific requirement). Among the chemicals of concern, lead and PBDEs have been shown to be present in many e-waste sites. If burning is being carried out, then chemicals such as PAHs should be measured. The presence of dioxins can be assumed if PAH levels are higher than normal (the cost of the dioxin analysis and the technology needed are limitations for low-income countries).

**Exposure assessment.** During site characterization the risk assessor (a health professional) should define the most vulnerable populations and their size, considering the activities in the site. An important issue for the selection of the study population is the sample size needed for the analysis of the biomarkers of exposure (which should be selected with results from the environmental monitoring). The assessor has to take into account exposed vulnerable groups such as children (all ages up to 18 years) and women (aged 18–49 years).

**Health effects.** To facilitate interventions at primary level, a well prepared risk assessment with reference to environmental levels of toxicants may be sufficient. Clinical assessment and surveillance with reference to key biomarkers of exposure can, however, increase awareness of the need for risk reduction and a primary health care programme. However, for children and women heavily exposed to toxic materials in e-waste sites, a health

surveillance intervention framework should be introduced. The surveillance should include a clinical examination and a follow-up scheme. The participation of poison control centres in this step may be important, as clinical toxicology is relevant for health surveillance.

**Cumulative exposure.** In many e-waste sites other chemicals might be present (for example, pesticides in areas where spraying for dengue or malaria is common), other threats might become a health risk (for example, ultraviolet radiation or biological agents in water), and other factors may increase exposure (for example, scarcity of health professionals, poverty, cleanliness of the location, or presence of playgrounds in contaminated zones). Therefore, the risk assessor should consider all those elements during the site characterization, as they may have to be remediated simultaneously with e-waste-related pollution during the intervention.

### 3.3 Risk reduction to mitigate health impacts

#### 3.3.1 Elimination of child labour

Children who work are not always considered child labourers. Child labour is defined as work that deprives a child of their childhood, their potential and their dignity, and that is harmful to a child's physical and mental development (57). Child labour is a significant concern in regard to informal e-waste recycling work. As e-waste contains a range of toxic chemicals and metals, children who work with e-waste may be exposed to these hazardous materials. Therefore, children working with e-waste may be considered as child labour, as it may be detrimental to their physical and mental development. Children as young as 5 years of age have been reported working in the sorting, dismantling and recycling of e-waste (5, 19, 58).

Due to their young age and inexperience, children may not recognize occupational hazards and may be less aware of the proper uses and benefits of protective equipment. This combination puts children at greater risk of adverse health effects. Additionally, children are more easily manipulated than adults and are unlikely to be aware of their rights and the international conventions aiming to curb and eventually eliminate child labour (32). The ILO has two major Conventions that address child labour. The ILO Minimum Age Convention, 1973 (No. 138), aims to establish a minimum age for entry into employment and national policies for the elimination of child labour. It has been ratified by 172 countries (59). The ILO Worst Forms of Child Labour Convention, 1999 (No. 182), aims to prioritize the elimination of the worst forms of child labour. It has been ratified by 186 countries (25).

### 3.3.2 Sound occupational health measures

Extending basic social protection measures (including social security and health protection) to informal workers in the waste sector is a necessary first step towards reducing e-waste risks, ensuring access to occupational health provision, and eliminating child e-waste labour (60). Ministries of health can engage, together with ministries of labour, to ensure this transition. Recommended occupational safety and health safeguards include ventilation when work is conducted indoors; dust control; training in safe work practices; use of personal protective equipment (PPE); and medical surveillance (61).

Local and national governments can also regulate for and support investment in



engineering controls (dust control, cleaning methods, ventilation and air extraction, replacement of toxic solvents); good work practices (training, safe working methods, medical surveillance); and the use of PPE (resistant gloves, footwear, body protection, and respiratory protection, including particulate and chemical gas respirators) (29, 54).

The ILO in India has developed a checklist of risk reduction strategies for e-waste workplaces to assist e-waste workers in improving their safety, health and working conditions (62). The manual includes low-cost ideas using locally available materials that can be easily adopted by e-waste workers to improve safety, productivity and efficiency. The recommended measures highlight actions such as good personal hygiene, use of appropriate PPE and designated clothing that is only worn while working with e-waste. These measures can help reduce “take home” exposures and can help reduce children’s indirect exposure from parental work. Critically, pregnant women should not work in e-waste recycling.

However, further studies are needed to more precisely determine what occupational health measures yield comparatively greater health benefits for e-waste workers, particularly in informal and resource-limited settings. Measures that protect workers from acute injury are likely to be different from those that protect them and their families from longer-term exposure to the chemical toxicants of e-waste. For example, one study of health risks at the Agbogbloshie waste facility found that e-waste workers incurred both musculoskeletal injuries due to the excessive physical demands of inappropriate recycling methods and the effects of excessive exposure to air pollution. The study highlighted the potential for adapted ergonomic measures to address the former issue, but had few solutions to offer for the latter aside from increased use of PPE (63). Another study in Nigeria found low use of PPE and high prevalence of workplace

### Box 3.6 Occupational health hazards among informal e-waste workers

While more studies on the health risks of exposure to toxicants at informal e-waste recycling sites have been published over the past decade, fewer studies have been undertaken to compare the health status of formal and informal workers. For instance, a 2019 study in Chile found that the prevalence of chronic diseases among informal and formal e-waste workers was comparable to national rates, but that injuries and stress were more common among the informal workers, and could often be attributed to financial insecurity (65).

injury. However, even among those who did use PPE, 88% had experienced an injury in the six months of work preceding the study (64). Box 3.6 presents a brief summary of the status of research on occupational health hazards.

Overall, PPE is regarded as a less effective intervention than engineering controls. It can be expensive and ideally requires training and regular maintenance. Studies of PPE use in e-waste management have also found barriers to its use, including heat and discomfort (66). Interventions related to PPE must therefore be used as a component of other pollution control and occupational health and safety measures in e-waste workplaces, and should be linked to broader interventions to protect health in informal workplaces and settlements.

It is also important to note that PPE, even when used optimally, will not, on its own, provide sufficient protection for informal e-waste workers from all sources of exposure. Although children and adolescents should not be working in hazardous e-waste management, those that do are at risk from poorly fitting protective equipment that is designed for adult workers. Protective equipment can provide a false sense of safety. Nor does use of PPE provide

**Box 3.7****Risk reduction interventions at Agbogbloshie, Ghana**

In Accra, Ghana's Agbogbloshie e-waste site, one of the largest in Africa, the international non-profit organization, Pure Earth, in partnership with Green Advocacy Ghana, established a pilot e-waste recycling facility that aimed to improve basic health and safety conditions. The facility enables workers to safely and efficiently strip and recycle copper and aluminium, avoiding harmful burning of the plastic sheaths. The project has gone through multiple adaptations in response to lessons learned. For instance, the first machines used for metal stripping were found to be unsuitable for small wires and cables, and new machines had to be purchased to provide more suitable methods, including training of workers in their use. The Ghana Health Service supported the project with training within the facility and throughout Agbogbloshie (29, 68). Projects aimed at reducing air pollution continue at Agbogbloshie, supported by partnerships involving Green Advocacy Ghana, the German Federal Ministry for Economic Cooperation and Development, and the Ministry of Environment, Science, Technology and Innovation of Ghana. Currently, an incentive programme is being implemented to purchase cables from workers and scavengers, which are then sent to a secondary recycler for appropriate disposal. This project aims to reduce air pollution from cable burning while ensuring that workers do not lose their livelihoods (69).

appropriate protection for children living in e-waste recycling communities. There is insufficient research that is specific to the use and appropriateness of different types of PPE in the context of informal e-waste recycling work.

Another key barrier is workers' own awareness of the health issues that they face. One study undertaken in Agbogbloshie found that low levels of knowledge among workers about the hazards associated with their work reduced their interest in adopting new measures and technologies that would protect them better (Box 3.7) (67).

### 3.3.3 Reducing e-waste production in health facilities and related health risks

The health sector can lead the way by developing national policies and guidance as part of its own contribution to global e-waste. Although it is just one of many e-waste streams, the health sector contributes to global e-waste flows by discarding many different types of medical devices, such as some microscopes, electronic blood pressure monitoring devices and electrocardiogram machines (70). It is essential to correctly

determine the end status of a medical device after it has been decommissioned to ensure proper management, reduce waste, and minimize the risk of harmful exposure of personnel, the public and the environment. Decontamination is required for decommissioning both single-use and reusable medical devices (33).

To ensure the safe management of e-waste, health care facilities can:

- promote practices that reduce the volume of medical e-waste generated;
- educate and train health professionals on the current disposal mechanisms of medical e-waste;
- raise awareness of the risks from unsafe disposal of medical e-waste;
- integrate e-waste management plans into the management of health care facilities (70);
- develop health care facility e-waste registers (70);
- follow best practices in e-waste management and medical waste management procedures (70–72).

### 3.4 Building health sector capacity at the grass-roots level

Health professionals are trusted sources of guidance who can play a key role at the local level working directly with communities or through primary health care services. They are ideally positioned to educate communities and decision-makers and can start acting immediately.

Primary health care and community professionals are well positioned to play multiple roles in communities at risk (73). These roles are described further in the next section in terms of (a) becoming informed and raising awareness about e-waste hot spots and health impacts generally; (b) recognizing health signs of e-waste exposures and prescribing solutions; and (c) advocating policy action at local and district levels.

#### 3.4.1 Becoming informed and raising awareness

There is currently low awareness of the hazards of informal e-waste recycling among affected communities and workers (5, 64). In one study, 88% of e-waste workers did not know that they were exposed to hazardous chemicals through their work, and 90% did not worry about injury from their work (64). Workers in the informal economy may also not be aware of their rights (74).

Health professionals can become levers for change, first of all by learning to identify e-waste hot spots in communities – through their routine daily work, including home visits, paediatric or occupational environmental histories, and visits to known or suspected e-waste sites to observe risks and conditions first hand.

To meet present challenges, environmental health education should be included in graduate studies of all health professionals.

As this is not always a reality, health professionals can educate themselves through face-to-face interactions, postgraduate studies or e-learning, based on WHO e-waste training modules (54) or other valid training materials or courses, including those offered by children's environmental health units, the Agency for Toxic Substances and Disease Registry (ATDSR) and the Basel Convention. Professionals can then begin to raise awareness among their colleagues, community members and policy-makers of the risks from exposure to e-waste recycling and the importance of removing children from exposure. Pregnant women, parents of young children and other vulnerable groups should be targeted, as well as champion families with influence in recycling communities, who can therefore empower others. Outreach and educational activities need to be tailored to the local situation, taking into account the critical way in which households may depend on e-waste work for livelihoods (66).

To successfully remove children from e-waste hazards, there has to be a detailed understanding of how the work in the mostly informal sector is organized in different countries and local settings. Solutions have to include alternative livelihoods and options for education, otherwise already poor and vulnerable children and their families risk becoming further deprived and forced into even worse forms of child labour (such as prostitution or drug trafficking). This approach is described in the ILO Worst Forms of Child Labour Convention, 1999 (No. 182), and the Transition from the Informal to the Formal Economy Recommendation, 2015 (No. 204) (25, 73). ILO has implemented programmes across the globe to show how this can work in practice (75).

#### 3.4.2 Recognize health effects of exposure and prescribe solutions

Health professionals can identify e-waste-related risk factors through careful recording



of and reference to medical records (54). However, in communities where e-waste work is common, people do not have ready access to primary health care clinics or hospitals. Providing greater access to health care for communities near e-waste sites, as part of universal health coverage, decent work, and related social protection, is therefore a critical first step to any intervention.

At the primary care level, paediatric, environmental and occupational histories are low-cost tools useful in detecting and diagnosing health disorders associated with e-waste exposure (54). These simple tools ask questions such as:

- Do you know about any pollution problems in your neighbourhood?
- Do you know if cables or other materials are burned nearby?
- Does anyone recycle electrical or electronic devices in your home or surroundings?
- Do you know if anyone in your household or your neighbourhood has elevated blood lead levels? (54)

Detecting toxic exposures in the parents' work environment or in children's homes or neighbourhoods may also support diagnosis and treatment of disease.

Suspected cases of e-waste-related conditions can also be referred to poison centres or hospital toxicology departments, or more specialized occupational health centres or children's environmental health

units. Children's environmental health units support the management of children with known or suspected exposure to environmental toxicants, and the diagnosis, management and treatment of children with illnesses that are derived from environmental exposure (32, 76). When resources are available, biomonitoring should be considered as a part of a strategy to identify and address risks.

But even in the absence of sophisticated diagnostic tools, health professionals can still *prescribe solutions*. The most critical is removing a child from exposure to e-waste. If it is not possible to completely remove a child from exposure, health professionals can suggest transitional solutions that have some health benefit. Health professionals may further advise pregnant women and women of childbearing age on how to reduce toxic exposure. Given the expanding demand for e-waste workers, and the widespread environmental contamination documented in some communities, preventing exposure requires intensive work at the community level.

One intermediate option, however, is the earmarking of specific areas out of residential zones where e-waste recycling can be carried out. Having several small workshops located in a specific area makes it easier to organize an integral programme for risk reduction.

### 3.4.3 Lobby policy-makers at local and district levels

Front-line health professionals can use their knowledge of community circumstances and the risks of improper e-waste management to promote the implementation of action among mayors, local councils, school boards and community leaders.

After informal waste sites are cleaned up, or begin to operate in the formal system, the job is not complete. Legacy contamination may need to be addressed, as chemicals released by e-waste recycling can persist

#### Box 3.8 Multilayered intervention in Montevideo, Uruguay

Informal e-waste recycling in Montevideo, Uruguay, is often conducted in residential neighbourhoods or urban settlements located in low-income areas, occurring close to and even inside people's homes. Children are exposed to high levels of toxic chemicals through contaminated soil and through participating in recycling-related activities, such as gathering metals and burning cables. Blood lead levels measured in children living in these areas were high enough to justify the implementation of a primary intervention. The intervention was conducted through a partnership between Pure Earth, researchers and the local government (City of Montevideo). Researchers conducted outreach visits that included educational sessions for community members in e-waste recycling areas on environmental exposure pathways, such as hygiene, dust removal and nutritional practices. Additionally, lead-contaminated soils were removed and replaced with clean fill. The multilayered approach was found to positively correlate with a decrease in both lead concentration in soils and blood lead levels in children (29, 66, 77, 78).

and accumulate in the environment, posing a threat to health even after informal recycling activities have ceased (29). Environmental remediation of contaminated soils may be necessary to protect populations from ongoing exposure. Box 3.8 presents an example of a multilayered intervention in Uruguay.

## 3.5 Action research

Although research on e-waste exposure and health effects has grown significantly in the past decade, there are still many large gaps in knowledge, as described below.

- The majority of studies measuring both exposure to e-waste and health outcomes have been conducted in a few very well known sites. More studies on health effects, from a wide variety of regions and sites,

are necessary to give a more accurate understanding of the health outcomes in informal e-waste workers.

- Better understanding is needed of the long-term effects of exposure to e-waste, the effects of chemical mixtures from e-waste and the effects of low-dose exposures.
- There is also limited research documenting the most effective policies and interventions. Health researchers in government, NGOs, academia and the private sector should be encouraged to comprehensively evaluate interventions and make the results of those evaluations publicly available, including negative results. A platform for sharing experiences of interventions at the local, national and international levels should be established.
- Health professionals at local and municipal levels can contribute to field research on

the health effects of exposure to e-waste, mechanisms of action, prevention of exposure, the management of e-waste-related conditions, and effective interventions. A more detailed list of priority research areas is included in Box 3.9.

Action research – that is, research that tests interventions as they are implemented – can help address the economic, social and health needs of e-waste workers in an integrated way (Box 3.10). Research teams should be multidisciplinary, whenever possible, including professionals from health and the environment, labour and social sciences, and economics and development (66). The involvement of government authorities, regulators and inspectors in research efforts will help ensure uptake of interventions demonstrated to be effective.

Similarly, parents who are enlisted as active partners in research are more likely to support interventions (66).

### Box 3.9 Research priorities

#### Health effects

- Long-term, prospective cohort studies are necessary to study the long-term effects of exposure to e-waste in both children and adults. Because of the long latency period of some diseases and the high social and economic costs of chronic disease, long-term studies of childhood exposure are necessary.
- Given the unique mixtures of chemicals in e-waste, additional studies on exposure to chemical mixtures are needed. Further research into the combination and inhibitor effects of chemicals in e-waste is warranted.
- Additional research on emerging health outcomes of concern – such as hearing loss in children, olfactory memory in children, rapid onset of blood coagulation in children, fasting blood glucose levels in older adults, liver function, kidney injury, male reproductive and genital disorders, and sperm quality – should be conducted.
- Additional studies of health outcomes should be done in expanding e-waste areas in Africa, Asia and the Americas. Differences in the make-up of electronic equipment, recycling techniques, and the distribution of e-waste activities between sites mean exposures can vary significantly.
- As new and updated electronics are produced, research needs to focus on the additional exposure and environmental burdens that these items may add to the health of e-waste workers.

#### Interventions

- Document the effectiveness of awareness-raising, risk reduction interventions and prevention strategies and share this information.
- Conduct further research on environmental remediation technologies.
- Conduct research to develop more easily recyclable technologies with less toxic components (29, 79, 80).



**Box 3.10****Action research for better workers' health at Agbogbloshie, Ghana: GEOHealth West Africa Network**

The GEOHealth West Africa Network is an action research initiative of the University of Ghana, together with the University of Michigan and McGill University (81, 82).

The research aims to advance understanding of the health risks of the Agbogbloshie e-waste site and use study findings to inform more evidence-based national, regional and international policies to prevent workplace exposure to e-waste toxic materials and compounds. Specific research objectives include:

- characterize work-related, time-varying, job-specific exposures of e-waste recycling workers at the Agbogbloshie site, and assess biological markers of exposure to metals, organic compounds, and combustion products;
- estimate potentially increased lifetime, work-exposure-associated cancer risks;
- evaluate associations of exposure with measures of acute and chronic respiratory morbidity in workers.

Research activities included the creation of a new health post and technical training centre in Agbogbloshie, renovation of a football pitch, provision of direct support to community waste workers to access medical checks and services, community “durbars” to raise public awareness and provide information about risks and exposures, and engaging the Ghana National Health Insurance Authority to provide free health insurance for some community members (83–85).

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A photograph showing five men sitting on a tractor that is heavily loaded with electronic waste (e-waste). The tractor is piled high with various electronic components, including monitors, keyboards, and other hardware. The men are dressed in casual work clothes. The scene is set outdoors on a paved area, possibly a street or a recycling yard. The text "4. Way forward: WHO global leadership on reducing health impacts of e-waste exposure" is overlaid on the bottom left of the image.

**4. Way forward:  
WHO global  
leadership  
on reducing  
health impacts  
of e-waste  
exposure**



## Way forward: WHO global leadership on reducing health impacts of e-waste exposure

### 4.1 Role of WHO in protecting children from e-waste

The WHO Initiative on E-waste and Child Health, launched in 2013 after the WHO Working Meeting on E-waste and Child Health (Geneva, 11–12 June 2013) and issuance of the Geneva Declaration on E-waste and Children's Health (1), set out the following goals:

- increased access to the evidence and knowledge base;
- greater awareness about health impacts, particularly in children, and solutions for e-waste management;
- improved capacity of the health sector to identify risks, track progress and promote good e-waste policies in order to better protect children through exposure reduction;
- promotion of better monitoring of exposures to e-waste;
- work with other sectors to implement policies and actions that reduce harmful exposures;
- facilitation of research about e-waste and related health effects;
- facilitation of the development of country pilots to test and propose workable interventions that protect public health.

Beyond this report, WHO is working with international experts and its network of WHO collaborating centres on children's environmental health and compiling the existing research and knowledge on e-waste and child health, including systematic reviews and regional and global perspectives (2). WHO is working on capacity-building of health professionals through the WHO training package on children's environmental health for the health sector, including an e-waste training module. WHO is also collaborating with other United Nations and international agencies on a massive open online course (3, 4). Box 4.1 presents a list of published WHO resources that are relevant to reducing exposure to e-waste.

Recent World Health Assembly resolutions on the role of the health sector in taking action on chemicals and wastes and reducing air pollution request that WHO and the health sector report on, and implement actions related to, toxic wastes and waste burning in order to protect health. See Box 3.3 for the most relevant World Health Assembly resolutions related to e-waste.

WHO is also an active contributor to United Nations-wide efforts to spread awareness of e-waste through collaboration with other United Nations agencies and international organizations to produce reports, such as the 2020 Global E-waste Monitor (5, 6).

At regional and local levels, WHO is working on developing the first country pilots in Latin

America in collaboration with the United Nations Industrial Development Organization (UNIDO) and other United Nations agencies that aim to create a framework for protecting child health from e-waste exposures. WHO also has pilot projects planned for the African region. The pilot projects will include local advocacy and communication about risks to concerned communities, capacity-building of primary health care systems about risks, and capacity-building for monitoring and measuring improvements.

## 4.2 Action in the context of the SDGs: climate and health agendas

Extracting resources from waste electrical and electronic devices using safe extraction technologies not only reduces health risks, it also produces substantially less carbon dioxide (CO<sub>2</sub>) than mining the same materials, benefiting the environment and reducing climate emissions (22). In 2019 as much as US\$ 57 billion of raw materials could have been recovered if e-waste was recycled optimally (5).

The most recent United Nations Global E-waste Monitor found that, in 2019 alone, refrigerators and air-conditioners recycled in substandard condition released an estimated 98 million tonnes of CO<sub>2</sub> equivalents into the environment. In contrast, the 17.4% of e-waste produced in 2019 that was collected and appropriately recycled saved as much as 15 million tonnes of CO<sub>2</sub> equivalents from being released into the environment (5). Along with the carbon savings, sound recycling processes can reduce or eliminate the random release of the many other chemicals that are detailed in this report and that can harm the health of humans and the environment (Box 4.2).

Recognizing the potential co-benefits, the WHO Global Strategy on Health, Environment and Climate Change calls for population-based, intersectoral approaches (7). In order

### Box 4.1 WHO published resources relevant to reducing exposure to e-waste

- The Geneva Declaration on E-waste and Children's Health (2013) (1)
- Electrical/electronic waste and children's health: training for health care providers. Children's health and the environment: WHO training package for the health sector (2019) (3)
- The e-waste challenge MOOC (developed in collaboration with the Secretariat of the Basel, Rotterdam and Stockholm conventions) (2020) (4)
- Sustainable management of waste electrical and electronic equipment in Latin America (2015) (6)
- WHO Global Strategy on Health, Environment and Climate Change: the transformation needed to improve lives and well-being sustainably through healthy environments (2020) (7)
- Decommissioning medical devices (2019) (8)
- Air pollution and child health: prescribing clean air – summary (2018) (9)
- The paediatric environmental history. Recording children's exposure to environmental health threats: a "green page" in the medical record (2018) (10)
- Inheriting a sustainable world? Atlas on children's health and the environment (2017) (11)
- Don't pollute my future! The impact of the environment on children's health (2017) (12)
- Recycling used lead-acid batteries: health considerations (2017) (13)
- Chemicals roadmap (2017) (14)
- Reducing global health risks through mitigation of short-lived climate pollutants: scoping report for policy-makers (2015) (15)
- Endocrine disruptors and child health: possible developmental early effects of endocrine disruptors on child health (2012) (16)
- Childhood lead poisoning (2010) (17)
- Children's exposure to mercury compounds (2010) (18)
- Persistent organic pollutants: impact on child health (2010) (19)
- Children's environmental health indicators (CEHI): presenting regional successes, learning for the future – summary (2009) (20)
- Making a difference: indicators to improve children's environmental health (2003) (21)

**Box 4.2****Safer workplaces and low-carbon production using e-waste inputs: example from Jordan**

In 2018, an estimated 13 kilotons of electronic and electrical equipment were discarded by households in Jordan, and only 6.8% of that waste was recycled using sound environmental methods (5, 23).

E-TAFKEEK, established with support from the European Union's SwitchMed project, specializes in electronic waste recycling. The initiative aims to recycle e-waste in an environmentally friendly manner, while providing safe e-waste jobs in the broader economy (24). Recycled materials include portable computers, mobile phones and televisions. The facility is located in Al Zarqa city, which hosts some 52% of Jordan's industry, despite the city's residents representing only 4.8% of the national population. E-TAFKEEK's activities include dismantling, recycling and refurbishing computers and computer parts, supplying sorted materials to smelting factories, selling non-reusable computer parts and providing legal disposal services.

Additionally, the company has supported awareness-raising activities among school children in Al Zarqa, Amman and Irbid. These activities teach students about different types of hazardous waste, sorting of e-waste, and how e-waste can be better managed.

The initiative, in which PPE-clad employees work using modern equipment in an organized factory setting, is also an example of how shifting e-waste management to the formal sector can both reduce environmental impacts from e-waste and ensure better working conditions. This model is relevant to other countries in the region, where awareness of the hazards and negative health impacts of e-waste tends to be very low, and data are scarce and often outdated (25).





to tackle the e-waste problem, the health sector must reach out to other sectors that have the ability to make changes upstream reducing risks to health (Figure 3.2). Collaboration between national ministries of health, labour, industry and environment, and with the private sector, is vital. Such collaboration can ensure that health-promoting interventions are adopted across the value chain – from the design of equipment with less toxic components, to preventing occupational and community exposures through safer e-waste management. The safe management of e-waste will thus contribute to the achievement of multiple SDGs (Box 4.3) (26).

The large number of sectors and stakeholders involved in e-waste management is both a challenge and an opportunity. As part of the E-waste Coalition, WHO is currently working with a range of United Nations and other organizations to raise awareness, build capacities and more efficiently provide support to Member States to address e-waste challenges. This coalition includes the United Nations University, ILO, the International Telecommunication Union, the International Trade Centre, UNIDO, the United Nations Environment Programme, the United Nations Human Settlements Programme, the United Nations Institute for Training and Research, WHO, and the Secretariat of the Basel, Rotterdam and Stockholm Conventions (22).

### Box 4.3 SDG targets related to e-waste

The environment is embedded in the integrated SDGs and their targets, a number of which reflect the importance of tackling the devastating impacts of e-waste on children around the world.



#### **SDG 3 – Ensure healthy lives and promote well-being for all at all ages – sets as a target:**

**3.9:** By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.



#### **SDG 8 – Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all – aims to:**

**8.3:** Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services.

**8.7:** Take immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labour, including recruitment and use of child soldiers, and by 2025 end child labour in all its forms.

**8.8:** Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment.



#### **SDG 11 – Make cities inclusive, safe, resilient and sustainable – aims to:**

**11.6:** By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.



#### **SDG 12 – Ensure sustainable consumption and production patterns – includes:**

**12.4:** By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

**12.5:** By 2030, substantially reduce waste generation through prevention, reduction, repair, recycling and reuse.

The E-waste Coalition aims to raise awareness, increase knowledge and provide support to countries in the sound and sustainable management of e-waste through cooperation among United Nations organizations and their partners at all levels. The goals of the E-waste Coalition include (22):

- supporting countries to manage and reduce e-waste volume, with the aim of creating jobs, while protecting workers, human health and the environment;
- strengthening country capacity to formulate and implement integrated e-waste management policies and practical measures;
- creating inter-organizational cooperation and adding value to existing programmes, partnerships and projects by avoiding duplication of resources and efforts;
- increasing awareness and engagement of key e-waste stakeholders at global, regional, national and local levels;
- supporting the development of a circular economy;
- preventing illegal e-waste trafficking via transboundary movement by ensuring that it is carried out in line with international regulations;
- promoting opportunities for non-State actors to be involved in solutions to e-waste challenges.

### 4.3 Rights-based approach to child health

Exposure to e-waste, which in many settings includes toxic chemicals and heavy metals, unquestionably impacts the rights of the

child. According to the Convention on the Rights of the Child, every child has the inherent right to life and States are duty bound to ensure, to the maximum extent possible, the survival and development of the child (Article 6) (27). The child's right to life, survival and development is contingent upon the realization of the rights to the highest attainable standard of health (Article 24), and encompasses the right to a healthy environment, such as an adequate standard of living with safe food, clean water and adequate housing (Article 27).

Chronic exposure to e-waste and its toxic components leads to a situation where children through infancy, early childhood and adolescence are continually faced with violations and abuses of these rights, leading to violation of their bodily (or physical) integrity. For many children who do not have access to an appropriate justice system or an effective remedy, this is a further denial of their human rights.

Efforts that should be taken by Member States to respect, protect and fulfil child rights are not limited to violations that occur within their territory or jurisdiction. Member States have human rights obligations regarding the export of their e-waste. Furthermore, businesses themselves have responsibilities to respect child rights. Whether involved directly or indirectly in the production and use of electrical and electronic equipment, or linked to the disposal or export of electronic waste, business enterprises have a responsibility to respect the rights of the child by preventing children from being exposed to toxicants from their products and activities. All of the involved sectors – from the electronics and recycling industries, to investors and legal professionals – have a responsibility to respect child rights that are infringed by the unsound management of e-waste.



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# Annex 1.

# Literature review methods

For Chapter 2, on the health and development impacts of e-waste exposure, an abridged review of peer-reviewed publications on e-waste exposure and human health outcomes published since 2013 was conducted by two reviewers.

This review built upon the first systematic review of e-waste exposure and health outcomes (1). The medical research database PubMed was searched using the same search terms as the 2013 review, and studies were assessed using the same inclusion and exclusion criteria. Additional articles were identified by experts during peer review; 54 relevant studies were found.

Articles found in the 2013 review are also included in this publication, and additional peer-reviewed publications were used to provide background on the health impacts of individual chemicals, biological plausibility of health outcomes, and medical conditions.

In terms of Chapter 1, on e-waste trends, settings and exposure pathways, and Chapter 3, on policy actions, a focused literature review was undertaken to identify key articles of interest on (a) trends in e-waste production and management; (b) geographical distribution of e-waste sites; (c) populations living and working in e-waste settings; and (d) existing and proposed policies to address e-waste and health issues. These searches relied to the extent possible on systematic reviews of these topics by other authors and reports and reviews by other United Nations agencies and research institutes.

## **For the review of exposure and health impacts:**

- **Keywords and phrases searched:** e-waste, electronic waste, WEEE (waste electronic and electrical equipment), health, development, mental, education, behaviour, learning, psychological, psychiatric, environment, exposure, food, fish, human breast milk.
- **Inclusion criteria:** peer-reviewed studies that focused on the effects of e-waste exposure on physical health, mental health, education, crime or violence outcomes; studied the general population, e-waste workers, adults, adolescents or children; used the Basel Convention and European Union definition of e-waste; compared exposed to non-exposed individuals; used exposure measurements including serum levels, umbilical cord serum, and self-reported exposure; measured health outcomes diagnosed by health professionals, direct physical measurements, blood tests, standardized tests for educational outcomes, screening instruments, or self-reported health outcomes. Prospective and retrospective cohort studies, case-control and cross-sectional studies were included.

- **Exclusion criteria:** articles that did not investigate an association between e-waste exposure and physical health, mental health, education, crime or violence outcomes; investigated a health outcome for which there are no standardized diagnostic criteria; did not study human populations; or were reviews, abstracts, or letters to the editor.

For the policy and action section, peer-reviewed academic publications and grey literature, United Nations publications, and national and regional e-waste policy plans were consulted. Because e-waste is an emerging issue and research on e-waste and health interventions is limited, e-waste and health experts were consulted. Because of significant common features with hazardous waste management, lead battery recycling, artisanal and small-scale gold mining, and air pollution management, WHO publications on these topics were also consulted.

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# Annex 2.

## Estimates of numbers of waste and e-waste workers, including women and children

### A2.1 Estimates of waste workers globally

While there are no global estimates of numbers of e-waste workers, available data indicate that the informal sector plays a dominant role in waste management (1). At the same time, e-waste collection and recycling has become an integral part of the waste stream and thus the waste management cycle. As a result, estimates of numbers of informal waste workers generally, as well as gender distribution, provide insights into the numbers of women and children who might be exposed to e-waste hazards.

In terms of waste management generally, a number of estimates of total number of workers in the formal and informal waste workforce were identified in reports produced by the World Bank and International Labour Organization (ILO), as well as in the peer-reviewed literature, as follows.

- **ILO, 2018.** If a circular economy approach is applied, by 2030, global employment in the waste management sector is projected to increase by some 70%, or another 45 million jobs, suggesting that employment in the formal and informal sector is currently about 64 million people today. Since e-waste is the world's fastest growing waste stream, increasing three times faster than the world's population, many of these jobs, formal or informal, will be in e-waste processing (2).
- **ILO, 2019.** The source refers to an estimate of 19–24 million people in total employed in the waste sector, of which 15–20 million are employed in the informal waste sector (1) – though the source reference from a 2013 ILO report (3) is based on a calculation based upon data from South Africa contained in a journal paper by Bonner (2008), which states: "Calculated on the basis of C. Bonner" (4).
- **World Bank, 2018.** The source (5) estimates there are 15 million informal waste workers worldwide, based on papers by Medina (2008) (6) and by Binion and Gutberlet (2012) (7).

- **Linzner and Lange, 2013.** This paper, developed by the waste expert from the European Development Bank, estimates that there are 12.5–56 million people worldwide working in the informal waste sector. It is based on a meta-analysis of 100 studies of the waste sector and yielded 43 national and urban data sets, including from the three countries where the waste workforce is most prominent, Brazil, China and India (8).

Based on the available data, the estimate of Linzner and Lange (12.5–56 million) (8) was used in the study as the most robust estimate for the total informal waste workforce. It is likely that the upward side of the estimate (56 million) is more accurate today, both in light of the ILO 2018 report (9), which estimates the total waste workforce at 64 million people and with an estimated growth of 70% until 2030, as well as citations from the ILO 2019 report (1), indicating most waste workers are concentrated in the informal, rather than formal, waste workforce.

## A2.2 Estimates of women in the global waste workforce

According to an ILO statistical overview of the informal economy, there are 2 billion workers in informal employment worldwide, including about 740 million women (9).

Of the total numbers of informally employed women, about 11% of these women (81.4 million) are working in the industrial sector, of which waste is a part, compared to 22% of informally employed men (277.2 million), for a total of 358.6 million men and women informally employed in the industrial workforce (10). Based on data from an ILO statistical review (11) of total numbers of women in the informal economy, and the subsequent review (9) of gender distribution in the informal sector (10), it can be estimated that women constitute 23% of the total industrial workforce in the informal sector.

This means that within the informal industrial sector, of which waste is a subsector, the estimated proportions of female and male workers are 23% women and 77% men.

- **Order of magnitude estimate of women in the informal waste workforce.** While there are clear variations between regions and countries in terms of the proportion of women participating in the informal waste sector, based on the global estimated average of 23% of women in the informal industry workforce, and the most robust estimate of employment in the informal waste workforce by Linzner and Lange (12.5–56 million) (8), we arrived at an “order of magnitude” estimate *that some 2.9–12.9 million women worldwide may be working as informal waste labourers and are thus exposed to some level of e-waste hazards.*
- **Estimates of children in the informal waste sector.** Regarding children, some 152 million children aged 5–17 years are estimated by the ILO to be working in child labour, including over 18 million children (11.9%) in the industrial sector, of which waste processing is a major subsector (12). Some 73 million children worldwide are working in hazardous labour (12), with still uncounted numbers in hazardous roles in the informal waste recycling sector.



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# Annex 3.

## Country data tables

**Table A3.1**  
**E-waste generated by country and countries with e-waste legislation, policy or regulation in place in 2019**

Country	E-waste generated in kilotons	National e-waste legislation, policy or regulation in place
Afghanistan	23	No
Albania	21	Yes
Algeria	309	No
Andorra	—	—
Angola	125	No
Antigua and Barbuda	1.2	No
Argentina	465	Yes
Armenia	17	No
Australia	554	Yes
Austria	168	Yes
Azerbaijan	80	No
Bahamas	6.6	No
Bahrain	24	No
Bangladesh	199	Yes
Barbados	3.6	No
Belarus	88	No
Belgium	234	Yes
Belize	2.4	No
Benin	9.4	No
Bhutan	3.4	Yes
Bolivia (Plurinational State of)	41	Yes
Bosnia and Herzegovina	27	Yes
Botswana	19	No
Brazil	2 143	No
Brunei Darussalam	8.7	Yes
Bulgaria	82	Yes
Burkina Faso	13	No
Burundi	5.3	No
Cabo Verde	2.8	No
Cambodia	19	Yes
Cameroon	26	Yes
Canada	757	Yes

**Table A3.1**  
**E-waste generated by country and countries with e-waste legislation, policy or regulation in place in 2019,**  
 continued

Country	E-waste generated in kilotons	National e-waste legislation, policy or regulation in place
Central African Republic	2.5	No
Chad	10	No
Chile	186	Yes
China	10 129	Yes
China, Hong Kong SAR	153	Yes
China, Macao SAR	12	Yes
Colombia	318	Yes
Comoros	0.6	No
Congo	18	No
Cook Islands	—	—
Costa Rica	51	Yes
Côte d'Ivoire	30	No
Croatia	48	Yes
Cuba	—	—
Cyprus	15	Yes
Czech Republic	167	Yes
Democratic People's Republic of Korea	—	—
Democratic Republic of the Congo	—	—
Denmark	130	Yes
Djibouti	1.1	No
Dominica	0.6	No
Dominican Republic	67	No
Ecuador	99	Yes
Egypt	586	No
El Salvador	37	No
Equatorial Guinea	—	—
Eritrea	3.4	No
Estonia	17	Yes
eSwatini	7	No
Ethiopia	55	No
Fiji	5.4	No
Finland	110	Yes
France	1 362	Yes
Gabon	18	No
Gambia	2.7	No
Georgia	27	No
Germany	1 607	Yes
Ghana	53	Yes
Greece	181	Yes
Grenada	1	No

**Table A3.1**  
**E-waste generated by country and countries with e-waste legislation, policy or regulation in place in 2019,**  
 continued

Country	E-waste generated in kilotons	National e-waste legislation, policy or regulation in place
Guatemala	75	No
Guinea	11	No
Guinea-Bissau	1	No
Guyana	5	No
Haiti	—	—
Honduras	25	No
Hungary	133	Yes
Iceland	7.6	Yes
India	3 230	Yes
Indonesia	1 618	No
Iran (Islamic Republic of)	790	No
Iraq	278	No
Ireland	93	Yes
Israel	132	Yes
Italy	1 063	Yes
Jamaica	18	No
Japan	2 569	Yes
Jordan	55	Yes
Kazakhstan	172	No
Kenya	51	Yes
Kiribati	0.1	No
Kuwait	74	No
Kyrgyzstan	10	No
Lao People's Democratic Republic	17	Yes
Latvia	20	Yes
Lebanon	50	No
Lesotho	2.3	No
Liberia	—	—
Libya	76	No
Lithuania	34	Yes
Luxembourg	12	Yes
Madagascar	15	Yes
Malawi	10	No
Malaysia	364	Yes
Maldives	3.4	No
Mali	15	No
Malta	6.8	Yes
Marshall Islands	—	—
Mauritania	6.4	No
Mauritius	13	No

**Table A3.1**  
**E-waste generated by country and countries with e-waste legislation, policy or regulation in place in 2019,**  
 continued

Country	E-waste generated in kilotons	National e-waste legislation, policy or regulation in place
Mexico	1 220	Yes
Micronesia (Federated States of)	—	No
Monaco	—	—
Mongolia	17	No
Montenegro	6.7	Yes
Morocco	164	No
Mozambique	17	No
Myanmar	82	Yes
Namibia	16	No
Nauru	—	—
Nepal	28	No
Netherlands	373	Yes
New Zealand	96	No
Nicaragua	16	No
Niger	9.3	No
Nigeria	461	Yes
Niue	—	—
North Macedonia	16	Yes
Norway	139	Yes
Oman	69	No
Pakistan	433	No
Palau	0.2	No
Panama	40	No
Papua New Guinea	9.2	No
Paraguay	51	No
Peru	204	Yes
Philippines	425	Yes
Poland	443	Yes
Portugal	170	Yes
Qatar	37	No
Republic of Korea	818	Yes
Republic of Moldova	14	Yes
Romania	223	Yes
Russian Federation	1 631	No
Rwanda	7	Yes
Saint Kitts and Nevis	0.7	No
Saint Lucia	1.7	No
Saint Vincent and the Grenadines	0.9	No
Samoa	0.6	No
San Marino	—	—

**Table A3.1**  
**E-waste generated by country and countries with e-waste legislation, policy or regulation in place in 2019,**  
 continued

Country	E-waste generated in kilotons	National e-waste legislation, policy or regulation in place
Sao Tome and Principe	0.3	No
Saudi Arabia	595	No
Senegal	20	No
Serbia	65	Yes
Seychelles	1.2	No
Sierra Leone	4.2	No
Singapore	113	Yes
Slovakia	70	Yes
Slovenia	31	Yes
Solomon Islands	0.5	No
Somalia	—	—
South Africa	416	Yes
South Sudan	—	—
Spain	888	Yes
Sri Lanka	138	No
Sudan	90	No
Suriname	5.6	No
Sweden	208	Yes
Switzerland	201	Yes
Syrian Arab Republic	91	No
Tajikistan	—	—
Thailand	621	Yes
Timor-Leste	3.8	No
Togo	7.5	No
Tonga	0.3	No
Trinidad and Tobago	22	No
Tunisia	76	No
Turkey	847	Yes
Turkmenistan	39	No
Tuvalu	0	No
Uganda	32	Yes
Ukraine	324	Yes
United Arab Emirates	162	No
United Kingdom of Great Britain and Northern Ireland	1 598	Yes
United Republic of Tanzania	50	No
United States of America	6 918	Yes
Uruguay	37	No
Uzbekistan	—	—
Vanuatu	0.3	No
Venezuela (Bolivarian Republic of)	300	No

**Table A3.1**  
**E-waste generated by country and countries with e-waste legislation, policy or regulation in place in 2019,**  
 continued

<b>Country</b>	<b>E-waste generated in kilotons</b>	<b>National e-waste legislation, policy or regulation in place</b>
Viet Nam	257	No
Yemen	48	No
Zambia	19	No
Zimbabwe	17	No

— data not available.

Source: Forti et al. (1).

**Table A3.2**  
**Locations of informal e-waste dismantling and recycling sites reported in research literature**

Countries, territories, areas	Site name	Additional information reported in literature	Source
Bangladesh	Dhaka	In Bangladesh an estimated 20–30% of e-waste produced in the country is recycled appropriately.	(2)
Cameroon	Makea (Douala)	E-waste recycling is the primary economic activity that takes place in Makea.	(3)
Cameroon	New Bell (Douala)	The main economic activities in New Bell are e-waste recycling and food produce.	(3)
Cameroon	Ngodi (Douala)	A permanent population of more than 10 000 people live directly within the area where e-waste activities take place in Ngodi.	(3)
Chile	Santiago Temuco	Chile has the highest per capita production of e-waste in Latin America. Despite this, little research has been conducted on e-waste workers in the region. Yohannessen et al. (4) appears to be the first study on e-waste recyclers in Chile.	(4)
China	Guiyu	Guiyu is widely perceived to be the largest e-waste recycling site in the world. In Guiyu, more than 80% of families residing in the town are involved in the e-waste recycling industry, and research has suggested that there are more than 5500 e-waste businesses here, employing over 30 000 people. An estimated 20 million tonnes of e-waste are recycled here every year. In 2004, the e-waste recycling industry yielded approximately US\$ 10 million.	(5)
China	Qingyuan	Song and Li (6) found that dietary intake of PBBs from eggs were significantly higher in Qingyuan than in seven different food types tested in Taizhou. This suggests that Qingyuan faces more serious PBB pollution and exposure than Taizhou.	(6)
China	Taizhou	An estimated 2.2 million tonnes of e-waste are dismantled in recycling sites in Taizhou every year.	(5, 7)
China, Hong Kong SAR	Hong Kong SAR	In China, Hong Kong SAR, considerable amounts of land that were once used for agricultural purposes have been converted to other uses, including e-waste recycling, open burning and car dismantling workshops.	(8)
Egypt	None specified	Egypt is one of the largest-producing countries of e-waste in Africa. An estimated 15–20% of e-waste in Egypt is locally recycled, while the remainder is disposed of in landfills and incinerators. Currently, there are no records available about the extent of e-waste recycling work in Egypt or reliable estimates on the number of people working in this industry.	(9)
Ghana	Agbogbloshie (Accra)	An estimated 215 000 tonnes of second-hand consumer electronics are imported into Agbogbloshie every year. This area is home to approximately 40 000 people. It has been cited as one of the most toxic threats in the world.	(10–12)
India	Bangalore	E-waste recycling in Bangalore occurs through a range of formal and informal businesses. Ha et al. (13) conducted the first study on trace element contamination at e-waste sites in Bangalore.	(13)
India	Chennai	In the period 2002–2004, approximately 1320 tonnes of computer waste and 13 300 tonnes of mixed computer scrap were imported into Chennai.	(13, 14)
India	Mandoli Industrial Area (Delhi)	Mandoli Industrial Area in Delhi is a hot spot for extracting valuable metals from printed circuit boards, cables and batteries. Pradhand and Kumar (15) estimated that, at the time, informal e-waste recycling had been ongoing in this area for 10 to 12 years and employed between 700 and 1000 workers.	(15)
India	Moradabad	Estimates have suggested that 50% of all printed circuit boards in India end up in e-waste recycling in Moradabad.	(16)
Mexico	Mexico City	Studies on appropriate waste collection have indicated that 7–10% of e-waste produced in Mexico is collected and transferred to formal recycling companies.	(17)
Nigeria	Alaba International Market (Lagos) and Ikeja Computer Village (Lagos)	Alaba International Market in Lagos State, Nigeria, was founded in 1978 and is now the largest market for used and new electronic and electrical equipment in west Africa. E-waste recycling and electronic dismantling is believed to have started here in about 2010. The most common activity here is burning and dismantling items to recover copper, aluminium and other precious metals.	(18–20)



**Table A3.2**  
**Locations of informal e-waste dismantling and recycling sites reported in research literature, continued**

Countries, territories, areas	Site name	Additional information reported in literature	Source
Nigeria	Cemetery and Jubilee Road, St Michael's Road (Aba)	Studies found that e-waste recyclers interviewed at sites in Aba reported significantly higher use of PPE than other e-waste recycling sites.	(19, 20)
Nigeria	Ogunpa and Queens Cinema (Ibadan)	Studies have found that e-waste workers in Ibadan and Lagos were more likely to report injuries when compared to workers in Aba.	(19, 20)
Pakistan	Karachi	Karachi is the major location for e-waste recycling in Pakistan. In 2014, an estimated 12.46 kilotons of old computers were imported into Karachi from various countries.	(21, 22)
Pakistan	Lahore	Several areas in Lahore are known to be involved in e-waste recycling. E-waste is often dismantled and recycled inside rooms, with little ventilation.	(21, 22)
Pakistan	Faisalabad Gujranwala Peshawar	E-waste recycling, dismantling and refurbishment are undertaken in Faisalabad, Gujranwala and Peshawar. However, very little is known about e-waste recycling in these areas. It is believed to be on a smaller scale than that in Karachi.	(21, 22)
Pakistan	Islamabad	E-waste recycling here is on a very small scale compared to Lahore and Karachi. However, research has recorded small children working in e-waste recycling, working at tasks such as cleaning, dismantling and burning electronic items.	(21)
Philippines	Capulong (Manila)	Martin (23) found that the Philippines had only two recycling plants working with e-waste. It was estimated that the country needed 14 plants in order to deal with the amount of e-waste imported into and produced in the country.	(23)
Thailand	Nakhon Si Thammarat Province (southern Thailand)	Studies on e-waste recycling in Nakhon Si Thammarat Province in Thailand have been conducted across 25 different sites. Decharat (24) found that personal hygiene is an important protective factor in the health of e-waste workers.	(24)
Thailand	Sue Yai Utit (Bangkok)	Sue Yai Utit is a community of household workshops located in Bangkok, Thailand. E-waste dismantling activities have taken place here for more than 30 years. Very little is known about levels of contamination at this site.	(25)
Uruguay	Montevideo	Uruguay is the second-largest producer of e-waste per capita in Latin America. The most common e-waste recycling practice in Uruguay is open cable burning to obtain copper. This has been occurring in the country for at least 10 years. More than half of all cable burning activity in Uruguay occurs in the capital city of Montevideo.	(26)
Viet Nam	Bui Dau	Bui Dau is a small village in Viet Nam where e-waste processing has been occurring since the beginning of the 21st century. E-waste processing activities here include dismantling electrical wires and metals, shredding plastic into pellets and manual recycling of a range of different electronic items. E-waste recycling can often be found occurring in the same area in which livestock is raised. Soil samples from Bui Dau have shown high concentrations of toxic compounds, such as PCBs and PBDEs.	(27, 28)
Viet Nam	Trang Minh	Trang Minh is a small rural community with less than 80 households. As many as 30% of the households in Trang Minh are involved in e-waste recycling. Recycling operations are family based and often take place in the backyard of a house or within close proximity to the living area.	(28, 29)
Occupied Palestinian territory, including east Jerusalem	Hebron	E-waste processing sites in Hebron are largely involved in dismantling electronic items and the daily burning of large quantities of plastics and other metals to extract precious metals. E-waste recycling involves more than 1000 residents of Hebron, and often occurs in close proximity to residential and agricultural areas. The number of e-waste sites has more than doubled since 2007. Estimates have suggested that there are as many as 533 e-waste recycling sites in Hebron.	(30, 31)

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# Photos



Children break apart CRT (cathode ray tube) monitors to salvage metal from inside at Agbogbloshie dump.  
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Plastic from e-waste is piled high at Agbogbloshie dump.  
© Andrew McConnell/Panos Pictures



Filipino boys gather recyclable materials, mostly e-waste.  
© EPA/ROLEX DELA PENA



Electronic waste disposal site in Accra, Ghana.  
© Maniglia Romano/Pacific P/Sipa/Shutterstock



Women selling onions at a market near an e-waste dump in Ghana.  
© Kwadwo Ansong Asante



Small factory where used electronic appliances, such as fridges, are being recycled in India.  
© Dieter Telemans/Panos Pictures



A woman carries her baby through an electronic waste site, Ghana.  
© Shutterstock



An e-waste worker disassembles items in Ghana.  
© WHO / Abraham Thiga Mwaura



Open burning of wires to extract valuable material, Ghana.  
© WHO / Abraham Thiga Mwaura



Migrant workers sort plastic computer keyboard components at an e-waste recycling workshop in China.  
© Natalie Behring/Panos Pictures



Young girl selling small bags of water to workers at an e-waste dump in Ghana.  
© Fernando Moleres/Panos Pictures



E-waste dismantling for recycling and repair at the cooperative *Mãos Dadas* (Holding Hands) in Ribeirão Pires, the interior of São Paulo state, Brazil.  
© Jutta Gutberlet



E-waste factory, Guiyu town, Guangdong province, China.  
© Shutterstock



Dismantling light fixtures for recycling.  
© WHO / Blink Media – Tali Kimelman



A child being treated for lead poisoning has his blood pressure checked in a medical clinic in Montevideo, Uruguay.  
© WHO / Blink Media – Tali Kimelman



Workers transport a large stack of old computers on a small tractor in China.  
© Natalie Behring/Panos Pictures

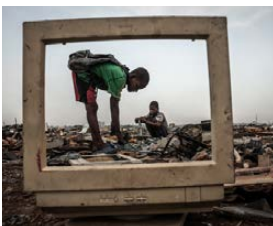


Palestinian school girls dispose of waste in an electronic dustbin at a school.  
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## **Children and digital dumpsites**

E-waste exposure and  
child health

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