Health risks related to environmental exposure in WEEE management

Prepared by:
Prof. Marco Vinceti, Prof. Fabriziomaria Gobba,
Dott.ssa Federica Violi, Dott. Alberto Modenese
Electrical and electronic products have become ubiquitous in today’s life around the planet.

- High consumer demand
- High obsolescence rate
- Short innovation cycles
- Low recycling rates

E-Waste contains significant amounts of toxic and environmentally sensitive materials and is, thus, extremely hazardous to humans and the environment if not properly disposed of or recycled.

Recently, for a growing number of people, in developing countries in particular, recycling and separation of e-waste has become their main source of income. In most cases, this is done informally, with no or hardly any health and safety standards, exposing workers and the surrounding neighborhoods to extensive health dangers as well as leading to substantial environmental pollution.

Health risks related to environmental exposure in WEEE management

The short- and long-term effects of exposure to hazardous e-waste substances are not fully understood and their study is complex.

- The toxicity of many individual substances found in e-waste is well documented, however some potential contaminants are uncommon and little work has been done on their effects.

- Because of the multitude of chemicals found in e-waste, it is hard to define the outcome of the exposition to the single compound.

- The interaction of the chemicals found in e-waste can also be greater than the effect of the single chemical.

- Even if the single chemical does not have harmful effects, the mixture may produce some.

- The effects of metabolites’ toxicity that can mediate the effects of chemical exposure have not been sufficiently studied.

(The global impact of e-waste) (Perkins, 2014)

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Several initiatives have attempted to raise awareness of the need for appropriate regulation to protect against the health consequences of improper e-waste recycling practices.

- The Basel Convention, 1989
- The Bangkok Statement on Children’s Environmental Health, 2002
- The Bali Declaration on Waste Management for Human Health and Livelihood, 2008
- The Busan Pledge for Action on Children’s Environmental Health, 2009
The WEEE life cycle, from generation, to reusal, treatment and disposal, may expose the population to chemicals already present in EEEs components (chemical elements, brominated flame retardants (BFR), non dioxin-like polychlorinated byphenyls (NDL PCBs)) or to chemicals released during e-waste combustion (polycyclic aromatic hydrocarbons (PAH), polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs, dioxin-like polychlorinated biphenyls (DL PCBs))

(Frazzoli, 2010)
Health risks related to environmental exposure in WEEE management

Heavy metals and halogenated compounds
- Mercury, Lead, Cadmium, Hexavalent Chromium, Selenium, Indium, Antimony, Barium, Silver, Cobalt, Molybdenum, Beryllium, Arsenic, Copper, Zinc, Nickel

Polybrominated diphenyl ethers (PBDEs) and other Flame Retardants (FRs)
- A group of synthetic organic chemicals with no known natural sources in the environment, except for a few marine organisms that produce forms of PBDEs that contain higher levels of oxygen. PBDEs are widely used in electronic equipment (plastic housings of TVs, computer monitor housings, video cassette tapes), textiles, building materials, upholstery, and various plastic products. (IARC)

Polycyclic aromatic hydrocarbons (PAHs)
- Polycyclic aromatic hydrocarbons (PAHs) belong to a class of ubiquitous pollutants. They are mainly formed by incomplete combustion of e-waste

Dioxins and Furans
- Dioxins are a group of chemically-related compounds that are persistent environmental pollutants and tend to accumulate in the food chain. It can occur as a contaminant in herbicides; it has been widely used as a defoliant during the Vietnam war; it may also be produced in thermal processes (incineration), in metal-processing and in the bleaching of paper pulp with free chlorine.

Polybrominated biphenyls (PBBs)
- PBBs are a group of halogenated hydrocarbons that can be found in plastics and used as fire retardants in many consumer products to make them difficult to burn. They have no known natural sources of PBBs.

Polychlorinated Biphenyls (PCBs)
- Polychlorinated Biphenyls (PCBs) are a group of synthetic organic chemicals, with no known natural sources in the environment.

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Health risks related to environmental exposure in WEEE management

Different exposure sources to these hazardous substances may occur, such as:

• Inhalation
• Contact with soil and dust
• Oral intake of contaminated locally-produced food and drinking water

The health risks that can result may be due to:

• repeated exposure
• continued exposure
• persistence and bioaccumulation in the environment and bioconcentration in the food chain
<table>
<thead>
<tr>
<th>Persistent organic pollutants</th>
<th>Component of electrical and electronic</th>
<th>Ecological source of exposure</th>
<th>Route of exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brominated flame retardants</td>
<td>Flame retardants for electronic equipment</td>
<td>Air, dust, food, water, and soil</td>
<td>Ingestion, inhalation, and transplacental</td>
</tr>
<tr>
<td>Polybrominated diphenyl ethers (PBDEs)</td>
<td>Dielectric fluids, lubricants and coolants in generators, capacitors and transformers, fluorescent lighting, ceiling fans, dishwashers, and electric motors</td>
<td>Air, dust, soil, and food (bio-accumulative in fish and seafood)</td>
<td>Ingestion, inhalation or dermal contact, and transplacental</td>
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<td>Polybrominated biphenyls (PBBs)</td>
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<td>Ingestion, inhalation or dermal contact, and transplacental</td>
</tr>
<tr>
<td>Polybrominated dibenzofurans (PCDFs)</td>
<td>Released as a combustion byproduct</td>
<td>Air, dust, soil, and food</td>
<td>Inhalation and ingestion</td>
</tr>
<tr>
<td>Dioxins</td>
<td>Released as a combustion byproduct</td>
<td>Air, dust, soil, and food</td>
<td>Inhalation and ingestion</td>
</tr>
<tr>
<td>Polychlorinated dibenzodioxins (PCDDs)</td>
<td>Released as a combustion byproduct</td>
<td>Air, dust, soil, and food</td>
<td>Inhalation and ingestion</td>
</tr>
<tr>
<td>Elements</td>
<td>Printed circuit boards, cathode ray tubes (CRTs), light bulbs, televisions, solder, and batteries</td>
<td>Air, dust, water, and soil</td>
<td>Inhalation, ingestion, and dermal contact</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>Anticorrosion coatings, data tapes, and floppy disks</td>
<td>Air, dust, water, and soil</td>
<td>Inhalation and ingestion</td>
</tr>
<tr>
<td>Chromium (Cr) or hexavalent chromium</td>
<td>Switches, springs, connectors, printed circuit boards, batteries, infrared detectors, semi-conductor chips, ink or toner photocopying machines, cathode ray tubes, and mobile phones</td>
<td>Air, dust, soil, water, and food (especially rice and vegetables)</td>
<td>Inhalation and ingestion</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>Thermostats, sensors, monitors, cells, printed circuit boards, cold cathode fluorescent lamps, and liquid crystal display (LCD) backlights</td>
<td>Air, vapour, water, soil, and food (bioaccumulative in fish)</td>
<td>Inhalation, ingestion, and dermal contact</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>Cathode ray tubes and metal coatings</td>
<td>Air, water, and soil</td>
<td>Ingestion and inhalation</td>
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<tr>
<td>Zinc (Zn)</td>
<td>Batteries</td>
<td>Air, soil, water, and food (plants)</td>
<td>Ingestion and inhalation</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>Batteries</td>
<td>Air, soil, water, and food (plants)</td>
<td>Ingestion, ingestion, dermal contact, and transplacental</td>
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<tr>
<td>Lithium (Li)</td>
<td>Batteries</td>
<td>Air, soil, water, and food (plants)</td>
<td>Ingestion, ingestion, dermal contact</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>Cathode ray tubes and fluorescent lamps</td>
<td>Air, soil, water, and food</td>
<td>Ingestion, inhalation and dermal contact</td>
</tr>
<tr>
<td>Beryllium (Be)</td>
<td>Power supply boxes, computers, x-ray machines, ceramic components of electronics</td>
<td>Air, food, and water</td>
<td>Inhalation, ingestion, and transplacental</td>
</tr>
</tbody>
</table>

WEEE and health issues

Scientific evidence so far comes mostly from studies carried out in China and Africa.

Among the potential health consequences associated with exposure to e-waste, different effects are reported in literature, such as:

• changes in lung function
• changes in thyroid and other endocrine function
• changes in mood, behaviour, cognitive development and mental health
• spontaneous abortions, stillbirths
• changes in birthweight and childhood growth rates
• cytotoxicity and genotoxicity
• carcinogenic effects
• endocrine disrupting properties

(Grant, Lancet 2013)
(Perkins, Ann Global Health 2014)
### Health risks related to environmental exposure in WEEE management

#### Thyroid function

<table>
<thead>
<tr>
<th>Thyroid function</th>
<th>Exposed setting</th>
<th>Exposed population</th>
<th>Primary toxicant</th>
<th>Health effect</th>
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</thead>
<tbody>
<tr>
<td>Ju et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Mothers and newborn babies (n=93)</td>
<td>Not assessed</td>
<td>Maternal: TSH higher (2.63 vs 2.10 mIU/L) and free T4 lower (16.47 vs 16.07 pmol/L) in exposed group. Cord blood: TSH (6.35 vs 5.47 mIU/L), free T4 (8.45 vs 9.52 pmol/L).</td>
</tr>
<tr>
<td>Yuan et al.</td>
<td>Formal recycling</td>
<td>Formal and informal workers vs not exposed (n=49)</td>
<td>PBDEs</td>
<td>Serum PBDE: 382 vs 158 ng/g lipid weight, p=0.045. Serum TSH: 1.7 x 10^-4 vs 1 x 10^-4 mIU/L, p=0.01</td>
</tr>
<tr>
<td>Zhang et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Pregnant women (n=50)</td>
<td>PCCDs and PCCFs, PCBs, and PBDEs</td>
<td>Higher body burdens of PCCD and PCCFs, PCBs, and PBDEs. Serum TSH: 1.15 vs 2.65 nmol/L, p=0.015. Free T4: 112.5 vs 139.0 nmol/L, p=0.015</td>
</tr>
<tr>
<td>Wang et al.</td>
<td>Ecological: workers in exposed town vs those in control town</td>
<td>Population (n=442)</td>
<td>PBDEs</td>
<td>Lower TSH (1.26 vs 1.57 μIU/mL), T3 (1632.4 vs 1817.2 μIU/mL), and free T3 (4188.8 vs 4404.4 μIU/mL), all p&lt;0.001. No difference in T4.</td>
</tr>
<tr>
<td>Han et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Population (n=369)</td>
<td>Not assessed</td>
<td>Serum TSH: 1.8 x 10^-4 vs 3.3 x 10^-4 mIU/L. No p value reported</td>
</tr>
</tbody>
</table>

#### Lung function

<table>
<thead>
<tr>
<th>Lung function</th>
<th>Exposed setting</th>
<th>Exposed population</th>
<th>Primary toxicant</th>
<th>Health effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zheng et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>School children (aged 8-13 years; n=144)</td>
<td>Chromium, manganese, and nickel</td>
<td>Blood manganese: 374.92 nmol/L vs 271.18 nmol/L, p&lt;0.01. Nickel: 5.3 vs 3.0 mg/L, p&lt;0.01. FVC in boys aged 8-9 years: 1859 vs 2121 mL, p=0.03. Decrease in FVC with increased chromium (11-year-old β=−14.02, p=0.018, 13-year-old β=−33.23, p=0.027), decreased FVC with increased nickel (10-year-olds β=−18.47, p=0.035)</td>
</tr>
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</table>

#### Reproductive health

<table>
<thead>
<tr>
<th>Reproductive health</th>
<th>Exposed setting</th>
<th>Exposed population</th>
<th>Primary toxicant</th>
<th>Health effect</th>
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</thead>
<tbody>
<tr>
<td>Guo et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Mother-infant pairs (n=220)</td>
<td>Lead, chromium, cadmium, and nickel</td>
<td>No differences in birthweight, birth length, or gestational age. Negative correlation between placental nickel and gestational age (r=-0.16, p=0.017)</td>
</tr>
<tr>
<td>Guo et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Mother-infant pairs (n=183)</td>
<td>PAHs</td>
<td>Cord blood total PAH: 10.85 vs 79.63 ppb, p=0.003; chromium: 1.57 vs 1.05 ppb, p=0.049; BaP: 2.14 vs 1.64 ppb, p=0.001. DahA 12.26 vs 11.59 ppb, p=0.031. Increased BaA, chrysene, and BaP in neonates with adverse birth outcomes (prematurity, low birthweight, still birth, and malformations) (p=0.05). BaA negatively associated with neonatal height (r=-0.23, p=0.006); chrysene and BaP negatively associated with gestational age (r=-0.20, p=0.013); r=-0.17, p=0.042, respectively. Higher total PBDEs in those with adverse birth outcomes (41.97 vs 9.88 ng/g, p=0.004). No effect on neonatal length, GA, or infant sex</td>
</tr>
<tr>
<td>Wu et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Mother-infant pairs (n=153)</td>
<td>PBDEs</td>
<td>Higher total PBDEs with adverse birth outcomes. Higher total PCBs with adverse birth outcomes (r=0.26, p=0.03). Negative associations between individual PCB congeners and neonatal height, neonatal weight, Apgar score, gestational age, and BMI (all p&lt;0.05)</td>
</tr>
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### Growth

<table>
<thead>
<tr>
<th>Study</th>
<th>Exposure</th>
<th>Population</th>
<th>Outcome</th>
<th>Measurement</th>
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<tbody>
<tr>
<td>Zheng et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>School children (aged 8-13 years; n=144)</td>
<td>Manganese and nickel</td>
<td>Height: 126.8 vs 135.0 cm, p&lt;0.001. Weight: 24.7 vs 30.2 kg, p&lt;0.001. BMI: 15.2 vs 16.5, p&lt;0.001. Negative correlations between serum manganese and height ($r=-0.303$, p=0.001) and weight ($r=-0.228$, p=0.006) and serum nickel and height ($r=-0.417$, p&lt;0.001), weight ($r=-0.399$, p&lt;0.001), and BMI ($r=-0.213$, p=0.011).</td>
</tr>
<tr>
<td>Huo et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Children (younger than 6 years; n=226)</td>
<td>Lead</td>
<td>Blood lead: 15.3 vs 9.94 mg/dL (p&lt;0.01). No differences in height, weight, chest circumference, or head circumference.</td>
</tr>
</tbody>
</table>

### Mental Health Outcomes

<table>
<thead>
<tr>
<th>Study</th>
<th>Exposure</th>
<th>Population</th>
<th>Outcome</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liu et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Children (aged 3-7 years; n=303)</td>
<td>Lead</td>
<td>Blood lead: 0.6-0.40 µmol/L (13.2 vs 8.3 mg/dL), p&lt;0.01. Temperament scores: activity level (mean SD 4.53±0.38 vs 4.61±0.81, t=3.37), adaptability (4.96±0.73 vs 4.67±1.83, t=2.96), and approach withdrawal (4.62±0.85 vs 4.3±0.89, t=2.87).</td>
</tr>
<tr>
<td>Li et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Newborn babies (n=152)</td>
<td>Lead</td>
<td>Cord blood lead: 11.3 vs 6.0 mg/dL, p&lt;0.001; meconium lead: 2.5 vs 1.2 mg/L, p&lt;0.001. NBNA scores: total: (38.45 vs 38.82, $t=2.23$, p=0.043), behaviour cluster: (10.91 vs 11.23, p=0.028). Negative associations between meconium lead and total NBNA ($r=-0.093$, p&lt;0.01), activity tone ($r=-0.637$, p&lt;0.01), and behavioural ($r=-0.826$, p&lt;0.01) scores.</td>
</tr>
</tbody>
</table>

### DNA Damage

<table>
<thead>
<tr>
<th>Study</th>
<th>Exposure</th>
<th>Population</th>
<th>Outcome</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chen et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Population (n=138)</td>
<td>Micronuclei in binucleated cells: median 4.0% (range 2.0-7.0) vs 1.0% (0.0-2.0), p&lt;0.01. Micronuclei in binucleated cells: median 5.0% (range 0.0-96.0) vs 0.0% (0.0-5.0), p&lt;0.01. Micronuclei in binucleated cells: median 4.0% (range 2.0-7.0) vs 1.0% (0.0-2.0), p&lt;0.01. Positive correlation between blood lead and micronuclei in binucleated cells ($r=0.245$, p&lt;0.01). No associations with copper or chromium.</td>
<td></td>
</tr>
<tr>
<td>Yuan et al.</td>
<td>Recycling activity</td>
<td>Recycle workers vs farmers (n=49)</td>
<td>Lead, copper, and cadmium</td>
<td>Not assessed.</td>
</tr>
<tr>
<td>Wang et al.</td>
<td>Recycling activity</td>
<td>Recycle workers vs not exposed (n=104)</td>
<td>Lead, copper, and cadmium</td>
<td>Not assessed.</td>
</tr>
<tr>
<td>Liu et al.</td>
<td>Recycling activity</td>
<td>Recycle workers vs not exposed (n=201)</td>
<td>Positive correlation between blood lead and micronuclei in binucleated cells ($r=0.245$, p&lt;0.01). No associations with copper or chromium.</td>
<td></td>
</tr>
<tr>
<td>Li et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Newborn infants (n=302)</td>
<td>Chromium</td>
<td>Comet assay: DNA damage (3.2% vs 10.7%, p&lt;0.01), length of tail (4.49±1.92 µm vs 2.09±0.65, p&lt;0.01). Blood chromium correlated with DNA damage ($r=0.95$, p&lt;0.01) and tail length ($r=-0.95$, p=0.01).</td>
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</tbody>
</table>

### Gene Expression

<table>
<thead>
<tr>
<th>Study</th>
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<th>Population</th>
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<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Newborn infants (n=423)</td>
<td>Cadmium</td>
<td>Metallothionein expression in placenta: 67.0% vs 3.7%, p&lt;0.01; and correlated with cord blood (r=-0.21, p=0.01) and placenta (r=-0.76, p=0.01) cadmium concentrations.</td>
</tr>
<tr>
<td>Zhang et al.</td>
<td>Ecological: exposed town vs control town</td>
<td>Pregnant women (n=105)</td>
<td>Placental S100P protein (0.026 vs 0.032, p=0.043) and mRNA (0.175 vs 1.462, p=0.001). Metallothionein expression (0.051 vs 0.035, p=0.003).</td>
<td></td>
</tr>
</tbody>
</table>

Health risks related to environmental exposure in WEEE management

Children’s health

• Higher exposure for children than for adults
• Children have a decreased ability to detoxify substances
• During growth, a child’s developing systems are significantly more sensitive to damage
• Children often spend more time outdoors, where hazardous exposures are within closer proximity
• Young children typically exhibit hand-to-mouth behavior and crawl on the ground, which predictably leads to the direct ingestion of potentially harmful substances
Health risks related to environmental exposure in WEEE management

ACTION C.2
Evaluation of environmental, economic, social and health benefits generated by the project

Indicators of progress:

- **Types and amounts of Waste Electrical and Electronic Equipment (WEEE) with the greatest potential for adverse health effects**
  - on workers processing electronic waste
  - on the general population

- **Health risks assessment at e-waste processing, recycling and storage areas**
  - for the workers
  - for the general population
  - with associated quantification type and number of incident cases of potentially associated diseases

- **Types and amounts of health risks** associated with reuse of e-waste components

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WEEE associated contaminants

- Polybrominated diphenyl ethers (PBDEs)
- Dioxins
- Furans
- Polychlorinated Biphenyls (PCBs)
- Polybrominated biphenyls (PBBs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Lead
- Mercury
- Aluminium
- Antimony
- Cadmium
- Hexavalent chromium
- Selenium
- Nickel
- Lithium
- Barium
- Beryllium
- Zinc

Bibliographic research
For each category of WEEE a representative product has been considered:

- **R1**: Refrigerants
- **R2**: Washing machine
- **R3**: Cathode ray tube (CRT)
- **R4**: Laptop
- **R5**: Fluorescent lamp
Cancer risk from heavy metal exposure in recycling waste of electrical and electronic equipment: preliminary results from the WEEENmodels European Life Program

• We conducted a health risk assessment to evaluate the cancer risk derived from environmental and occupational exposure to trace elements from different recycling procedures
  • electronic scrap in blister copper
  • treatment of metals recovery in copper smelter
  • treatment of shredding
  • pyrometallurgical treatment of Li-ion battery

• We considered the typical production of WEEE in a municipality of 150,000 inhabitants, where a Life Cycle Assessment (LCA) was carried out.
• **Outdoor** (1km² around a WEEE treatment plant) and **indoor** (factory volume of 3200m³) emissions generated from the above-mentioned procedures were computed, to perform a health risk assessment for occupationally-exposed workers and for the general population around the plant.

• Dose of the heavy metals cadmium, nickel, arsenic inhaled by the potentially exposed population was estimated using the values obtained through a toxicological model.

• Cancer risk due to inhalation was calculated using the method proposed by the California Office of Environmental Health and Hazard Assessment.
• For the heavy metals considered, generated from WEEE treatment, these **preliminary results** show negligible cancer risk for the general population.

• On the converse, some risks may be present for occupational exposures linked to specific procedures (from cancer risk of $1.42 \times 10^{-3}$ for men working in shredding procedure and exposed to nickel to cancer risk of $4.68 \times 10^{-4}$ for women working with electronic scrap and exposed to arsenic).