

E-WASTE AND RAW MATERIALS: FROM ENVIRONMENTAL ISSUES TO BUSINESS MODELS

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BACKGROUND

This book is the result of the EU project **E-mining@schools**, which is co-funded by an international consortium consisting of **EIT RAW Materials** in collaboration with eleven international partners. The aim is to raise knowledge and awareness among students regarding the environmental and ethical considerations and business opportunities related to e-waste and its lifecycle. Educational activities include in-class teaching facilitated by a digital platform.

The publication targets lower/upper secondary and vocational schools and the society at large. The book provides teaching materials for teachers on the topic of waste electric and electronic equipment (WEEE)¹, raw materials and their life cycle and their importance for sustainability objectives. The book introduces and explains in a popular science manner different concepts, such as critical materials, circular economy and the social and environmental aspects of e-waste. Special focus is placed on critical raw materials and urban mining.

¹ In legal documents the definition of waste electric and electronic equipment (WEEE) and electric and electronic equipment (EEE) are often used, but for simplicity we will use “e-waste” and “e-products”.

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1. E-WASTE AND RAW MATERIALS

1.1. What is e-waste?

Electric and Electronic Equipment (EEE) could be defined as products that rely on either electric current or electromagnetic fields to work. This includes equipment that generates, transfers or measures electric currents or electromagnetic fields. A practical way to recognize e-products is to identify whether a power supply or a battery is required for the equipment to work properly. An e-product becomes electrical and electronic equipment waste (e-waste) when its owner discards the whole product or its parts without an intention to re-use it. The WEEE Directive (2012/19/EU) is the main law within the European Union designed to regulate the management and ultimately reduce the amounts and the environmental and health risks associated with e-waste.

E-waste is a complex waste stream as it includes a great variety of materials including different plastics and metals, some of which could be both highly valuable and hazardous if not managed

properly. Colloquially, e-waste is usually referred to as electronic waste, e-waste or e-scrap. Typical examples of e-waste² are discarded computers, TV-sets, household power tools, whitegoods or cell phones. It is the fastest growing waste stream in the EU and globally (European Commission 2018). For instance, in 2016 there was around 44.7 million tonnes of e-waste generated globally, and this is expected to reach roughly 52.2 million tonnes by 2021 (Baldé, Forti et al. 2017).

The WEEE Directive (2012/19/EU) classifies e-waste into the following groups (for explanations and examples, see Table 1):

- Temperature exchange equipment;
- Screens, monitors, and equipment containing screens;
- Lamps;
- Large equipment (any external dimension of more than 50 cm);
- Small equipment (no external dimension of more than 50 cm);
- Small IT and telecommunication equipment (no external dimension of more than 50 cm).



2) The main difference between electrical and electronic equipment is that electrical circuits do not have any decision-making capability, (i.e. processing capability) while electronic circuits do (<https://brightknowledge.org/engineering/electrical-and-electronic-engineering-what-s-the-difference>).

E-waste groups	Examples
Temperature exchange equipment	Refrigerators, Freezers, Equipment which automatically deliver cold products, Air-conditioning equipment, Dehumidifying equipment, Heat pumps, Radiators containing oil and other temperature exchange equipment using fluids other than water for temperature exchange
Screens, monitors, and equipment-containing screens	Screens, Televisions, LCD photo frames, Monitors, Laptops, Notebooks, Tablets, eBook-/e-Readers
Lamps	Straight fluorescent lamps, Compact fluorescent lamps, Fluorescent lamps, High intensity discharge lamps -including pressure sodium lamps and metal halide lamps, Low pressure sodium lamps, LED lamps.
Large equipment (any external dimension of more than 50 cm)	Washing machines, Clothes dryers, Dishwashing machines, Cookers, Electric stoves, Electric hot plates, Luminaires, Equipment that reproduce sound or images, Musical equipment (excluding pipe organs installed in churches), Appliances for knitting and weaving, Large computer-mainframes, Large printing machines, Copying equipment, Large coin slot machines, Large medical devices, Large monitoring and control instruments, Large appliances which automatically deliver products and money, Photovoltaic panels; Household appliances; IT and telecommunication equipment; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3.
Small equipment (no external dimension of more than 50 cm)	Vacuum cleaners, Carpet sweepers, Appliances for sewing, Luminaires, Microwaves, Ventilation equipment, Irons, Toasters, Electric knives, Electric kettles, Clocks and Watches, Electric shavers, Scales, Appliances for hair and body care, Radio sets, Digital cameras, Video cameras, Video recorders, Hi-fi equipment, Musical instruments, Equipment reproducing sound or images, Electrical and electronic toys, Sports equipment, Computers for biking, diving, running, rowing, etc., Smoke detectors, Heating regulators, Thermostats, Small Electrical and electronic tools, Small medical devices, Small Monitoring and control instruments, Small Appliances which automatically deliver products, Small equipment with integrated photovoltaic panels. Household appliances; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3 and 6.
Small IT and telecommunication equipment (no external dimension of more than 50 cm)	Mobile phones (smartphones, phablets etc.), GPS and navigation equipment, Pocket calculators, Routers, Personal computers, Printers, Telephones.

Table 1. Groups of e-waste in the EU and examples (EWRN 2017)

1.2. What raw materials are present in e-waste?

The e-products contains many electronic components, which in turn are made from a variety of raw materials providing highly diverse and specific electro-physical properties and characteristics – anything from insulation to conductivity. More than 60 elements from the periodic table may be found in materials and components used in electronics (Baldé, Forti et al. 2017). Although the largest part of them by weight is represented by metals and plastics, the materials used in electronics can be classified into 4 main groups.

1. Metals

Many different metals could be found in electronic products. Steel and iron are the main ones that account for about 50% of the products' weight. Other common and well-known materials are aluminium and copper, used for their high conductivity and malleability (good characteristics for shaping and mashing). Several other metals, such as nickel, chromium, lead, silver, gold or tin are used in resistors, capacitors and transducers. The majority of these other metals are used in much smaller amounts.

2. Rareearth elements

Rare earth elements (REEs) are a group of lanthanides series, scandium and yttrium (17 elements in total). REEs are usually used in small or very small amounts, but they are vital for many high-tech applications, in, for instance, permanent magnets, batteries, lasers and phosphors (Bristol 2015).

3. Plastics and other petroleum-based materials

Plastics are the second largest group of materials used in electronic products and constitute about 20% of e-wastes by weight. Plastics are mainly used in electronics for their insulating

and heat-resistant characteristics (Cato 2017). In the EU, around 2.6 Mt of plastics is used annually for the production of electric and electronic products, which corresponds to 5.6 % of the total global demand for plastics in the EU.

4. Minerals and non-metallic materials

Some metalloid (or semimetal) materials, such as silicon, are also used in e-products, enabling many of their key technical features. Silicone and its derivatives are the main substrate material in the production of microchips and semiconductors. Other non-metal or semimetal materials are antimony, bismuth, cobalt, fluorite, garnet, magnesium and talc. Other materials like ceramics are also used for its insulation characteristics. Certain clays, glasses, calcium and carbon (in various forms) are also often used.

Hazardous substances

Many electronic products contain hazardous materials, such as heavy metals (e.g. mercury, lead, cadmium, chromium, etc.) (Baldé, Forti et al. 2017). These cause risks to human health and the environment by entering into human food chains and ecosystems and bio-accumulating in living tissues. Other hazardous substances include, for instance, brominated flame retardants used in plastics, which have similar negative effects. The highest risks of exposure and harmful health effects are often due to improper management/recycling of e-waste, which, for example, can directly affect workers at waste management sites or indirectly affect society at large by leaching into the soil and water, harming microorganisms, disrupting ecosystems and entering into food chains though complex bio-accumulation mechanisms. Some examples of toxic substances and their possible health risks are exemplified in Table 2.

Gold - Printed circuit boards, computer chips (CPU), connectors / fingers
Silver - Printed circuit boards, computer chips, keyboard membranes, some capacitors
Platinum - Hard drives, circuit board components
Palladium - Hard drives, circuit board components (capacitors)
Copper - CPU heat sinks, wiring and cables, printed circuit boards, computer chips
Nickel - Circuit board components
Tantalum - Circuit board components (some capacitors)
Cobalt - Hard drives
Aluminium - Printed circuit boards, computer chips, hard drives, CPU heat sinks
Tin - Printed circuit boards, computer chips
Zinc - Printed circuit boards
Neodymium - Hard drives (magnets)

Box 1. Examples of metals and REEs used in different electronic appliances.

Hazardous elements	Examples of applications	Effects
Lead (Pb)	Used in the glass of CRT monitors (both TV and computer), circuits, solder in printed circuit boards, lead acid batteries	Carcinogenic (can cause cancer), neurotoxic (can cause damage to nervous systems), reprotoxic (toxic effect on reproduction processes), endocrine disruptor, persistent, bio-accumulative (tends to accumulate in organisms) and toxic. The effects are most damaging in-utero and to children.
Mercury (Hg)	Used in fluorescent light tubes, flat screen monitors, tilt switches, cell phones, etc. According to some studies, each electronic device contains at least a very small amount of Hg.	Carcinogenic, neurotoxic, reprotoxic effects, persistent toxin, endocrine disruptor, bio-accumulative characteristics. Exposure to Hg is very damaging to foetuses and small children.
Cadmium (Cd)	Mostly present in Ni-Cd batteries, light-sensitive resistors, and corrosion-resistant alloys for marine and aviation environments. The sale of Ni-Cd batteries (except medical ones) has been banned in the EU.	Carcinogenic, repro- and neuro-toxic, mutagenic, endocrine disruptor.
Brominated Flame Retardants (BFRs)	Used to reduce the flammability of plastics in most e-products. Includes polybrominated biphenyls (PBBs), polybrominated diphenyl ether (PBDEs) decabromodiphenyl (DecaBDE) and octabromodiphenyl (OctaBDE) ethers etc.	Endocrine disruptor, persistent, Bio-accumulative and toxic. Effects include impaired development of the nervous system, thyroid problems and liver problems.

Table 2. Examples of hazardous materials present in e-waste and its hazardous effects (Chen, Dietrich et al. 2011)

1.3. The criticality of materials: What is critical? Why? When?

Some of the above-mentioned materials are used in small or even trace quantities, but they may hold severe environmental significance or economic importance. Some of these materials are defined as **critical** due to the increasing mismatch between supply and demand, high price volatility or politically-induced limitations of supply (Bakas, Herczeg et al. 2016).

In 2011, 2014 and finally 2017, the EU has been releasing lists of materials defined as “critical” for society and welfare. The most recent list of 2017

contains 27 materials (Table 3), which are dominated by different metals including rare earth elements (light rare earth elements (LREEs) and heavy rare earth elements (HREEs)³ and platinum group metals (PGMs).⁴ The criticality of these materials is defined by two main criteria: importance to the economy and high supply risks (Figure 1).

Our economy cannot fully function without certain materials. The bio-medical, transportation, renewable energy and defence sectors (to name a few) rely on products, technologies and infrastructures, which demand an increasing variety of exotic materials that were not essential in the past. For instance, in the 17th century the

3) The REEs are a chemical group called lanthanides, which includes 17 elements that are broken into two categories according to their atomic weight: light and heavy. The LREEs group consist of 8 elements: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), HREEs includes the rest of the lanthanides (9 elements) such as dysprosium, yttrium (Y) and terbium.

4) PGMs - Platinum group of elements (also called as platinoids, platinides, platidises, platinum group, platinum metals and platinum family elements) are 6 noble, precious metallic elements clustered together in the periodic table: ruthenium (RU), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir), and platinum (Pt).

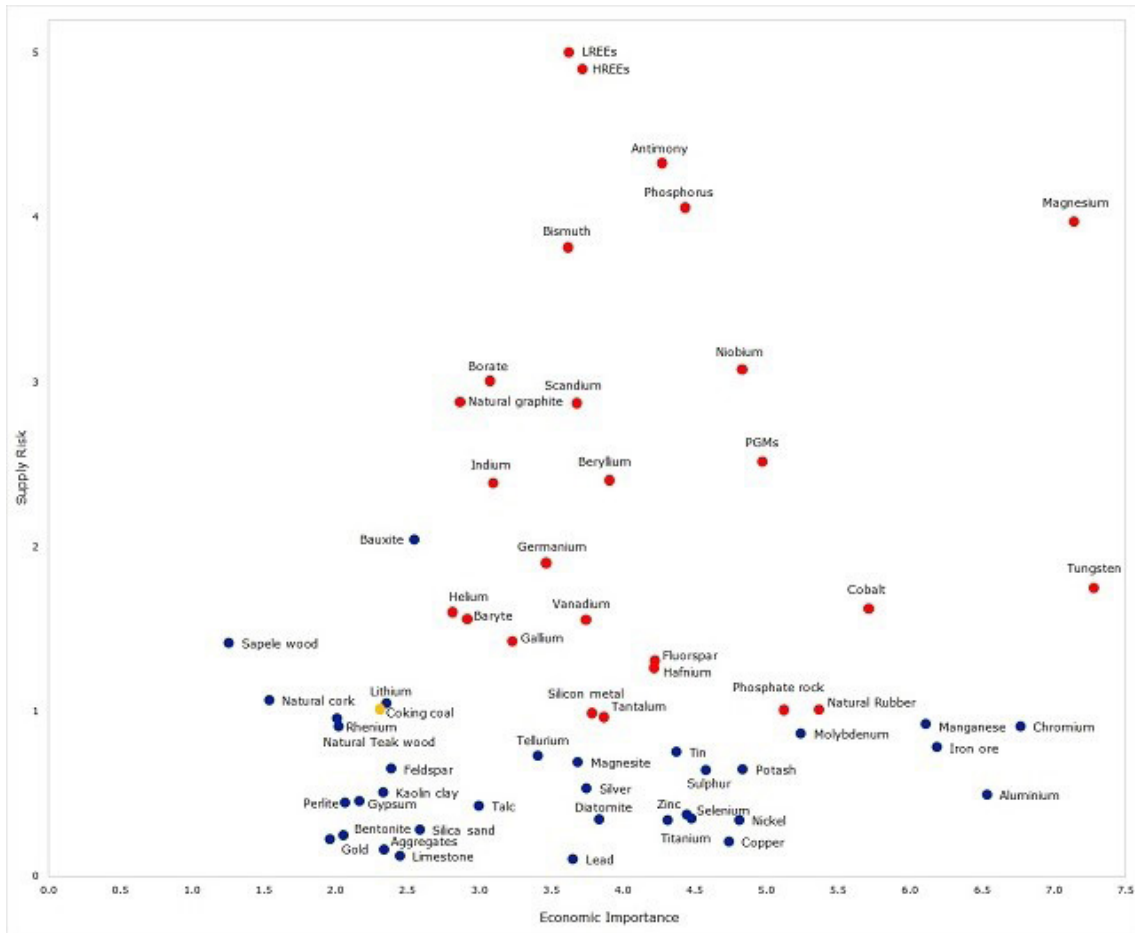


Figure 1. The list of critical materials (in red) in the EU and their supply risks and importance to the economy (European Commission 2017).

dominant technology for power production were wind- and water mills, which were based on common materials such as calcium, coal or iron. The emerging industrial revolution during the 17th and 18th centuries increased the demand for an increasing number of other materials (Figure 2). Today many materials that provide advanced features to several new products and innovative technological solutions are increasingly "exotic". In effect the modern economy would not survive without materials that represent almost the entire periodic table.

Many critical materials are used in electric and electronic equipment and their manufacturing processes. Although usually used in very small quantities, they provide important properties to electronic products. For instance, the semiconductor sector demands significant shares of the global use of several critical materials, such as Antimony, Beryllium, Cobalt, Germanium,

Antimony	LREEs
Baryte	Magnesium
Beryllium	Natural graphite
Bismuth	Natural rubber
Borate	Niobium
Cobalt	PGMs
Coking coal	Phosphate rock
Fluorspar	Phosphorus
Gallium	Scandium
Germanium	Silicon metal
Hafnium	Tantalum
Helium	Tungsten
HREEs	Vanadium
Indium	

Table 3. List of critical materials for the EU (European Commission, 2017).

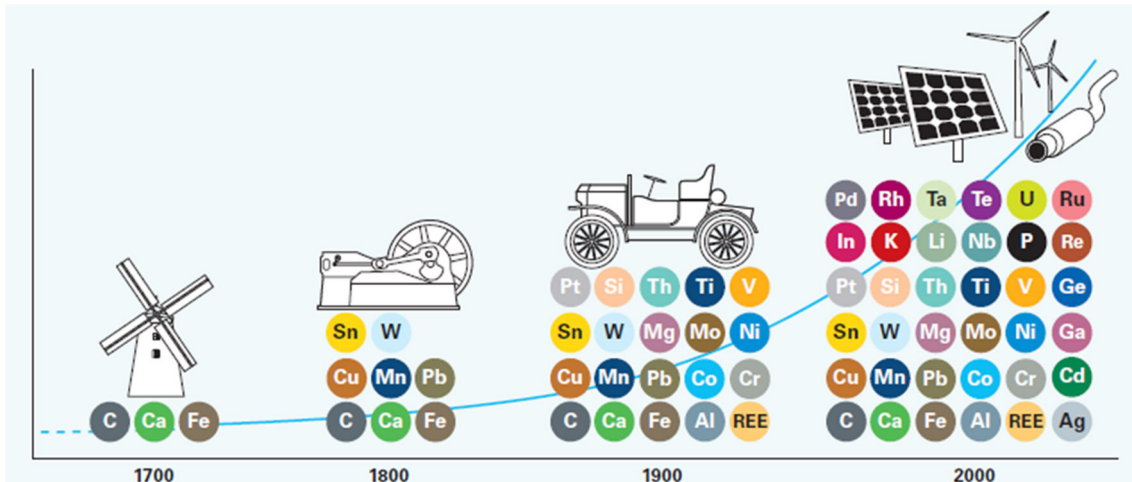


Figure 2. Use of elements from the historical perspective (Zepf, Simmons et al. 2014).

Indium, PGMs, natural graphite, REEs, silicon metal, and Tungsten (Figure 3).

A mobile phone, for example, can contain up to 50 different types of metals, many of which are noble and/or rare earth metals, such as Gallium, Indium, Niobium, Tantalum, Tungsten, Platinum Group Metals. All of these metals enable semiconductor miniaturization, lightweight and many “smart” functions. Indium is needed to enable touch-screen functionality; rare earth elements

(e.g. yttrium, terbium, europium) are essential for screens to produce different colours; lithium and cobalt are used in batteries to extend their capacity and service life; ultra-pure gold, silver and platinum are used in microchips as inter-connects in circuitry, while different rare-earth metals enhance different semiconductor properties (Figure 4). The quantities of these metals are very small. For example, the average weight of content of cobalt in a smartphone is around 2% of total weight,

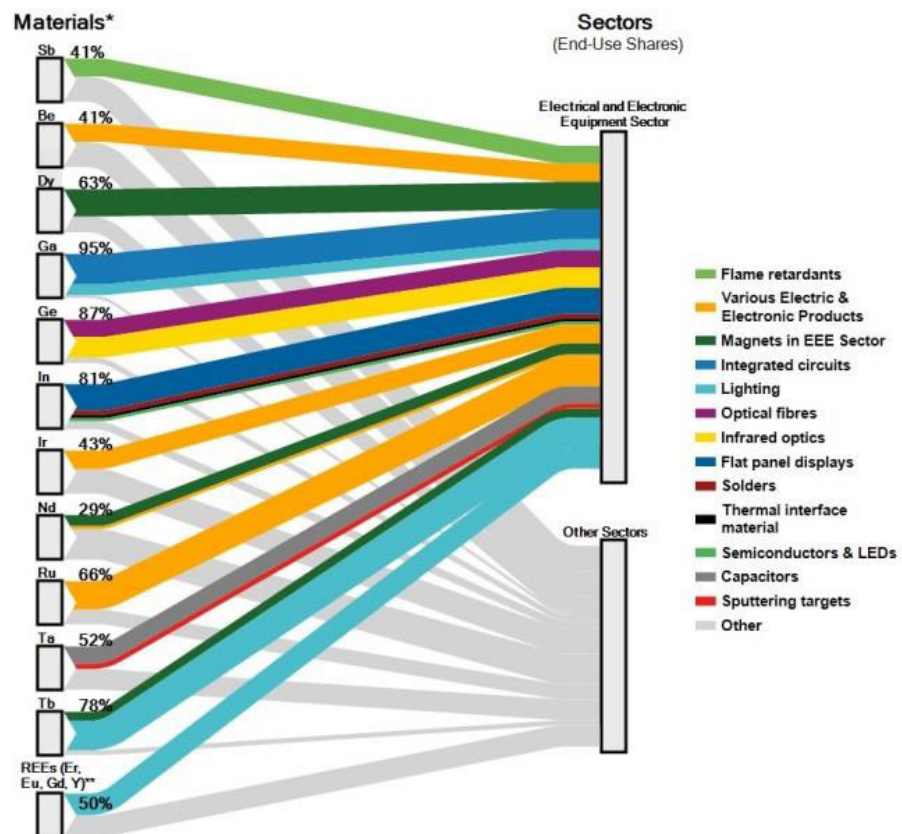
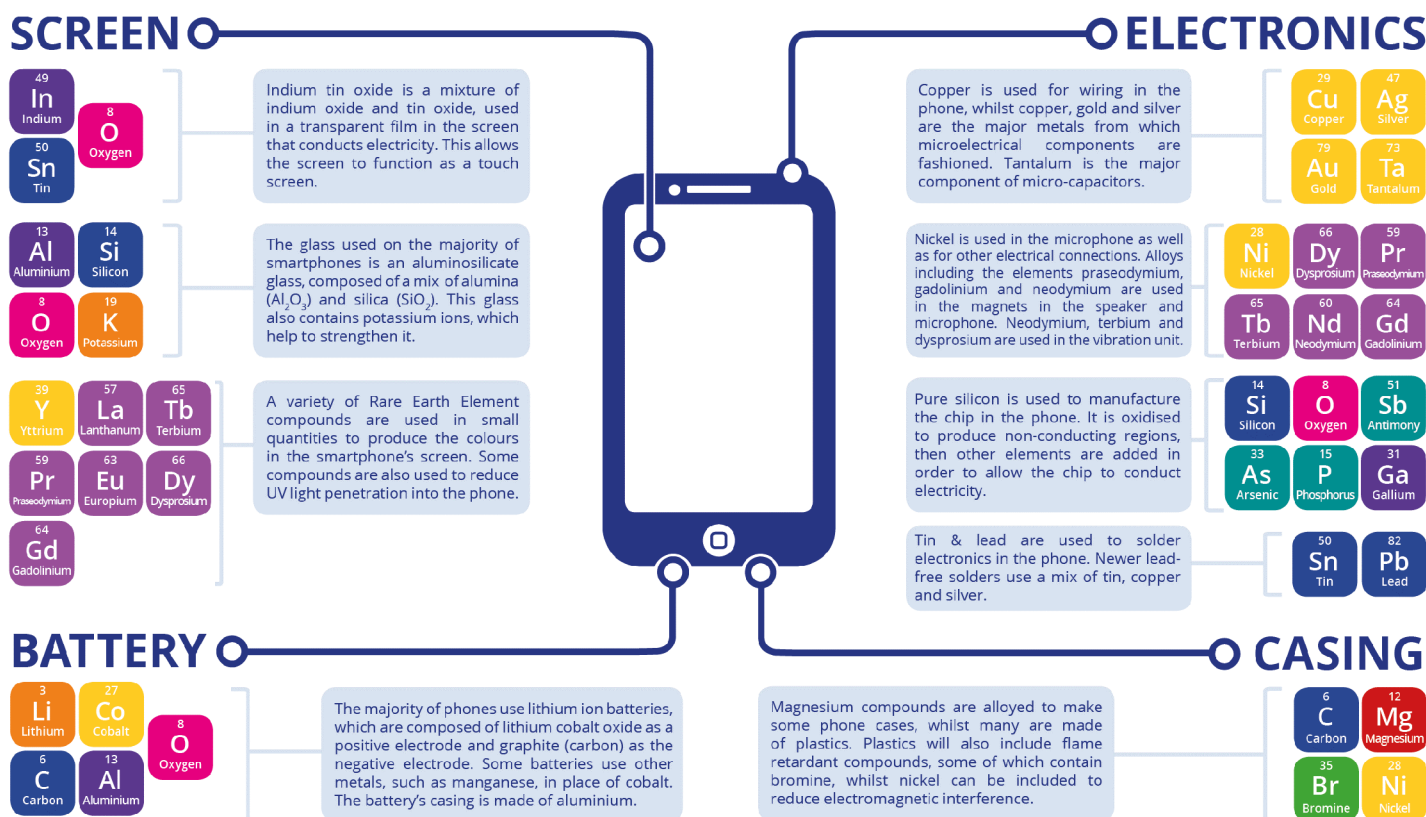


Figure 3. Share of critical raw materials used by the electric and electronics sector (Mathieux, Ardente et al. 2017).

ELEMENTS OF A SMARTPHONE

ELEMENTS COLOUR KEY: ● ALKALI METAL ● ALKALINE EARTH METAL ● TRANSITION METAL ● GROUP 13 ● GROUP 14 ● GROUP 15 ● GROUP 16 ● HALOGEN ● LANTHANIDE



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Figure 4. Examples of different elements required for a smartphone to function (Compound Interest 2015).

gold - 0.009%, beryllium - 0.001%, palladium - 0.004% and other materials are present in even smaller quantities (Bakas, Herczeg et al. 2016).

Other applications of critical materials include the so-called sustainable future technologies, such as solar panels, windmills, energy efficient lamps (e.g. LED) and electric cars. The demand for such technologies is increasing exponentially and so is the demand for exotic materials. For example, the rare earth metals neodymium (Nd) and praseodymium (Pr) are needed in the production of the permanent magnets that are used in wind turbines and electric vehicles. This demand is estimated to increase by approximately 250% over the next ten-year period. Other rare earths are also needed for the production of electric vehicles (especially batteries and electric motors) - on average 1-2 kg more than in conventional cars.

This increasing demand is reflected in price developments. For example, the price of neodymium and praseodymium increased by about 60% over 3 months in 2017, a year when approx. 4 million electric vehicles were sold globally. The annual production of electric vehicles is projected to grow to 50 million in 2030. Similar price trends are also predicted for lithium and cobalt used in the production of batteries in electric vehicles (SGU 2018).

Today, the growing demand for some of these materials is reaching the limits of supply, and several materials have been labelled as critical. For instance, indium is an inherently scarce metal. Economically viable proven global resources have been estimated at 11,000 tonnes. At current consumption rates indium should run out around year 2030 after which the prices may skyrocket (Randers, 2012).

Several materials (e.g. rare metals⁵) may not necessarily be critical due to their natural physical scarcity. Their criticality can also be determined by other contextual factors, such as price inelasticity⁶, uneven geographical distribution or politically induced access limitations (Erdmann and Graedel 2011). Many critical materials are mined and produced outside the EU and some are supplied by politically unstable countries or countries practicing policies of economic protectionism. See Figure 5, Figure 7 and Figure 6 for the distribution of important critical materials around the world.

For example, 90% of the global antimony supply (important for making smartphones) is in China. Moreover, China extracts more critical materials than any other country and has almost a monopoly in the production of some materials, as it is the main producer for 18 out of 27 CRMs. Several years ago, China restricted the export of some rare earth elements due to an increase in domestic demand and the environmental damage caused by their extraction. The restriction caused a signi-

ficant price disturbance on the global commodity market. For instance, the price of dysprosium oxide increased from 166 USD in 2010 to almost 1,000 USD per kg in 2011 (Guardian, 2015).

Other examples can be found in Africa. For instance, much of available tantalum is produced in Nigeria, Rwanda or Congo, while cobalt is mostly produced in Congo. In the last 20 years, these countries have experienced changes in government and significant political conflicts. Trading with some of these countries can also create political controversy in indirectly “supporting” undemocratic political regimes (see chapter 3).

The criticality of some rare metals is often discussed in political, economic and scientific discourses (TING and SEAMAN 2013) and most often in terms of the risks they pose to economic development. Much less frequently discussed is material criticality in terms of social and environmental dimensions. The extraction of RMs from natural resources is often concentrated in politically unstable countries with poor social protection and low environmental standards.

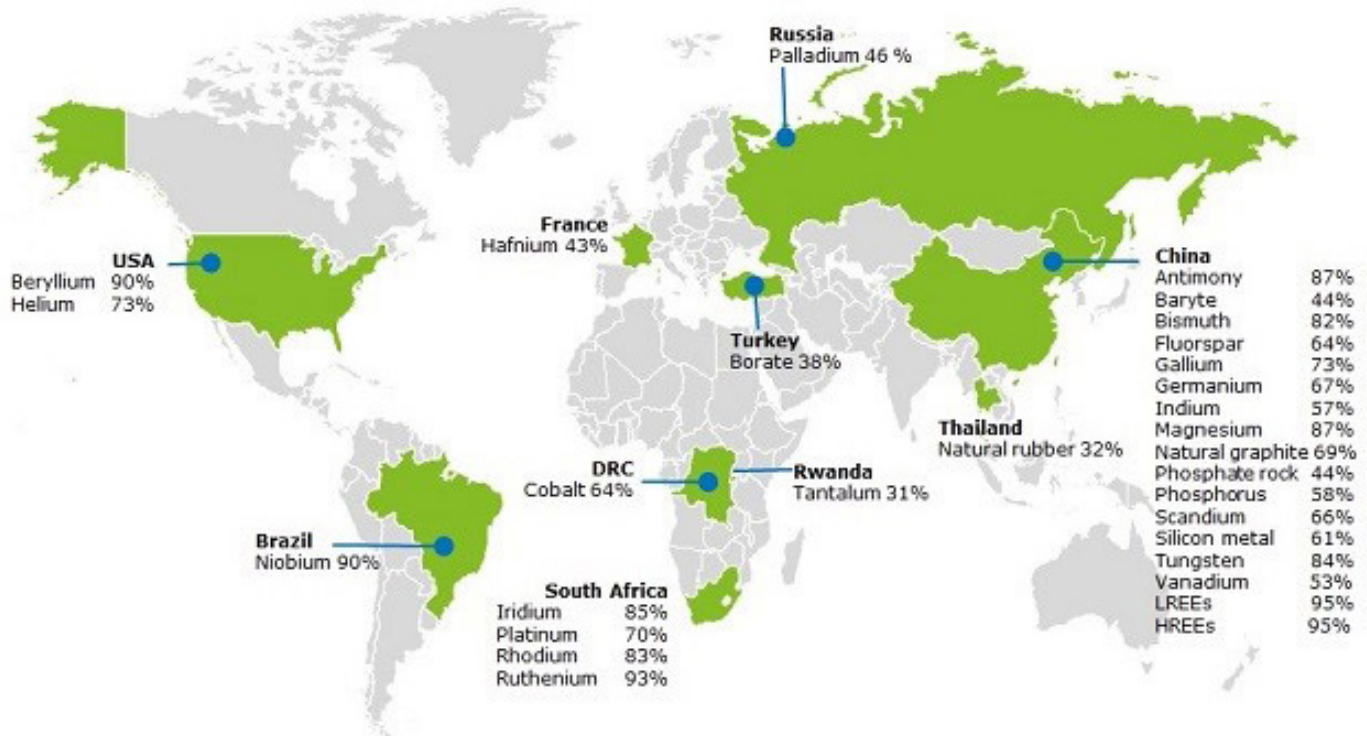


Figure 5. Share of global supply of critical materials (European Commission 2017).

5) The term ‘rare metals’ refers to all specialty metals, which includes rare earths, the platinum group, precious metals and other rare metals such as cobalt, gallium, germanium, indium, niobium, molybdenum, rhenium, selenium, tantalum and tellurium.

6) Price inelasticity implies that rising prices do not necessarily result in increased production.

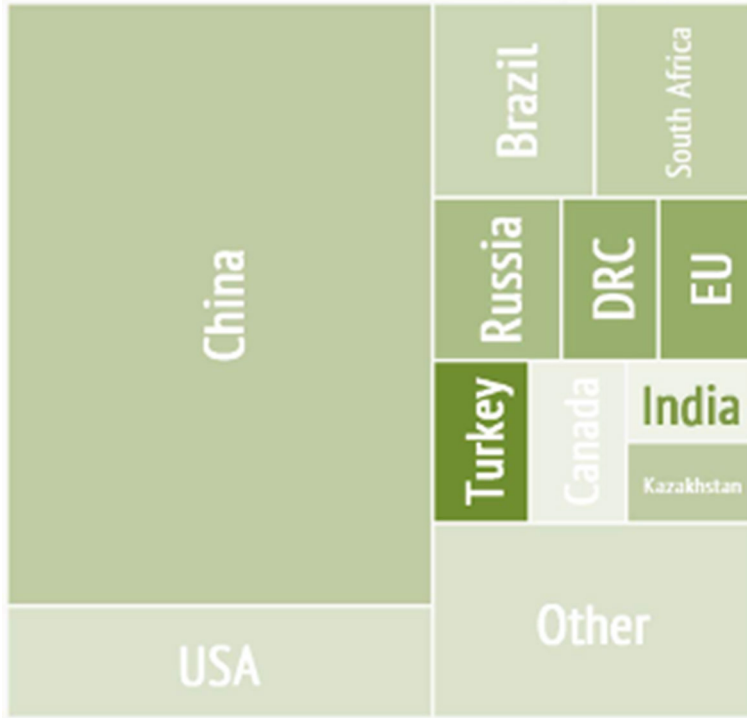


Figure 6. Share of critical material production among countries (European Commission 2017).

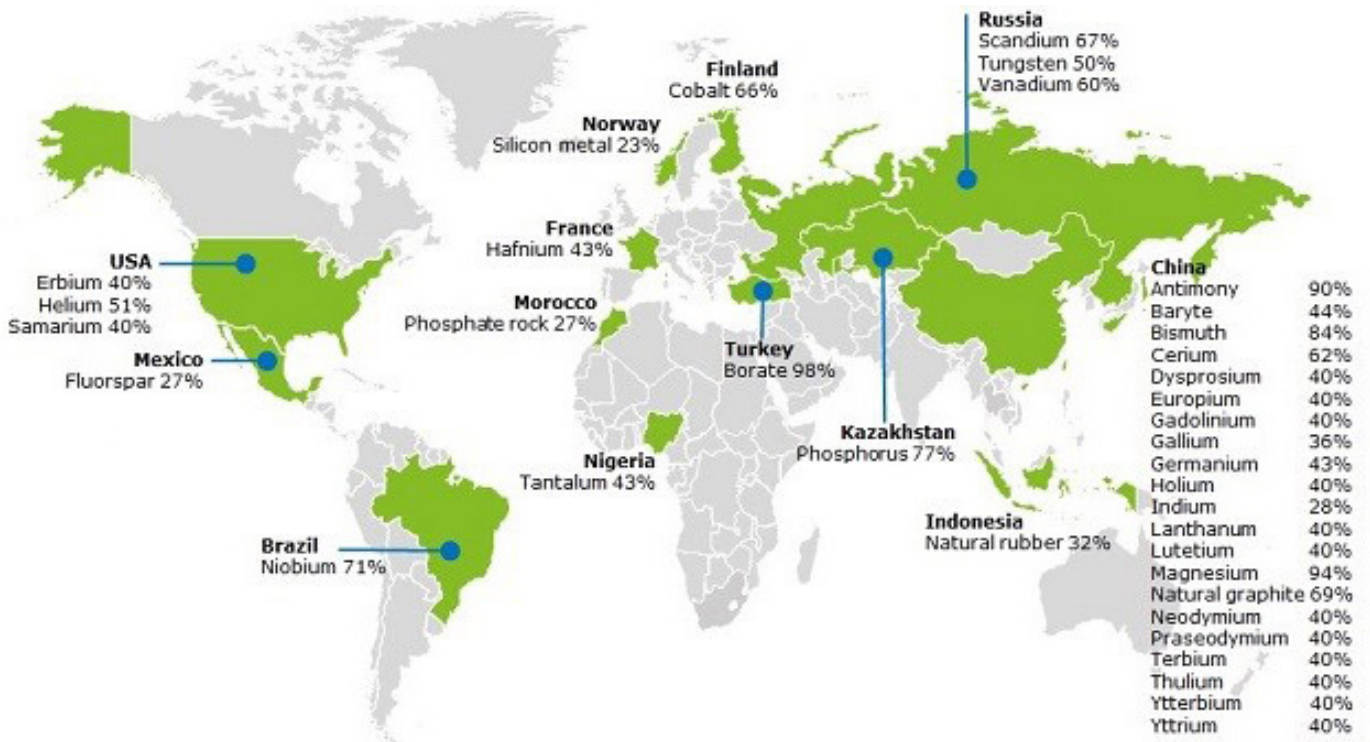


Figure 7. Share of EU's supply of critical materials (European Commission 2017).

2. ENVIRONMENTAL ASPECTS OF E-WASTE AND RAW MATERIALS

Besides economic and political issues, the critical materials sector is also associated with multiple environmental and social problems. The extraction of many raw materials is highly material- and energy-intensive and may cause significant environmental impacts from toxic pollution. For example, gold in mobile phones accounts for less than 1% of the device weight, but stands for over 50% of the total material requirement (TMR)⁷

induced by its production, and the weight-to-TMR ratios of other rare metals could be even smaller (Chancerel 2010). Moreover, issues such as child labour, poor social protection and unfair labour conditions are often associated with the extraction of these materials in some developing countries.

Consumers often lack the understanding about the overall environmental and social impacts



Figure 8. Life cycle stages of a smartphone (Modak 2014).

⁷ The TMR is an indicator referring to the so-called hidden material flows (i.e. the material rucksack) comprising all material flows associated with the processes in the lifecycle of a product or a service.

associated with their consumption. The most visible environmental aspect that consumers see is the amount of waste produced, but their understanding of the environmental impacts from production, use and even end-of-life management is rather poor. Developing life cycle thinking is important to guide consumer choices and product end-of-life management, such as sorting and recycling.

2.1. Life cycle thinking

In order to evaluate the environmental impacts of products along their entire value chain, the so-called **life cycle thinking or life cycle approach** is needed. These imply that environmental aspects are accounted for in all stages of the life cycle of a product (or service), from materials extraction to waste treatment (usually called “from cradle to the grave”). For instance, a

smartphone consists of a variety of metals, plastics, ceramics and many trace materials (Figure 8) and its life cycle begins with the extraction of these materials. At this stage, different environmental impacts are induced from the generation of air emissions, effluents and waste. The manufacturing stage of a smartphone requires hundreds of components and implies thousands of different processes, each demanding their own input materials and energy carriers and generating waste and emissions. The manufacturing of microchips, screens and batteries are highly resource intensive and generate significant amounts of waste. This is because the production of microchips requires ultra-pure input materials, which demands large amounts of energy for purification. Some of the ultra-pure inputs, such as gases, acids and water, are used in very large quantities. Moreover, the manufacturing of a smartphone implies

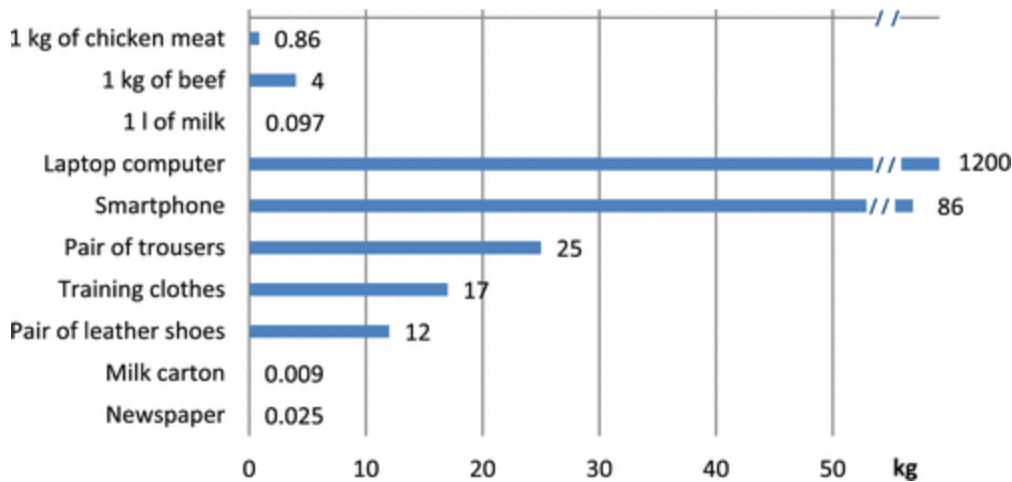


Figure 9. Waste footprint of 10 consumer products (Laurenti, Moberg et al. 2016).

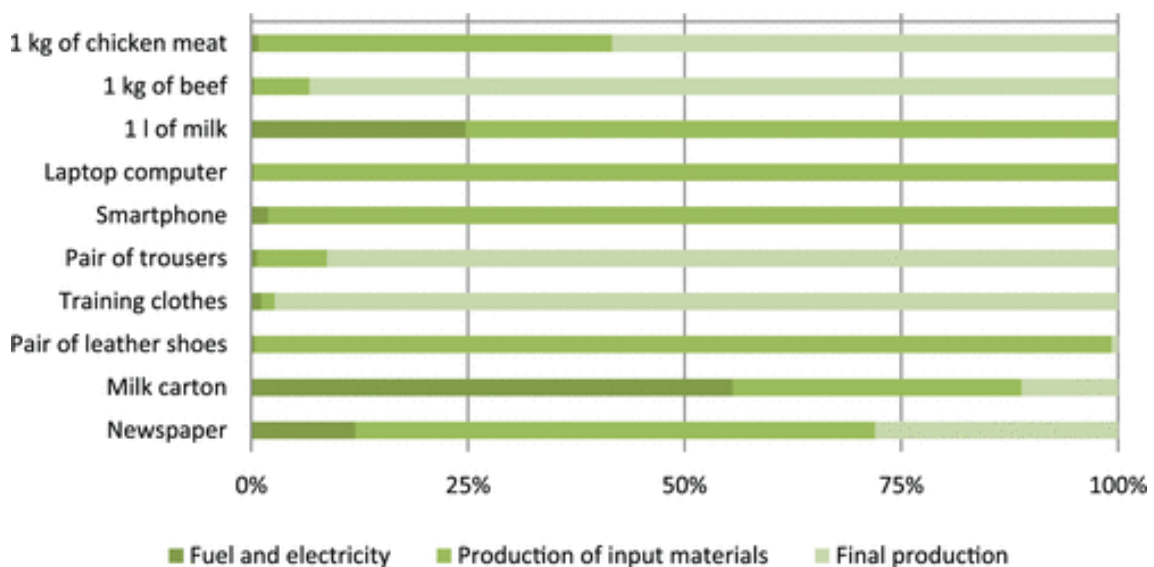


Figure 10. Waste footprint “distribution” between production stages (Laurenti, Moberg et al. 2016).

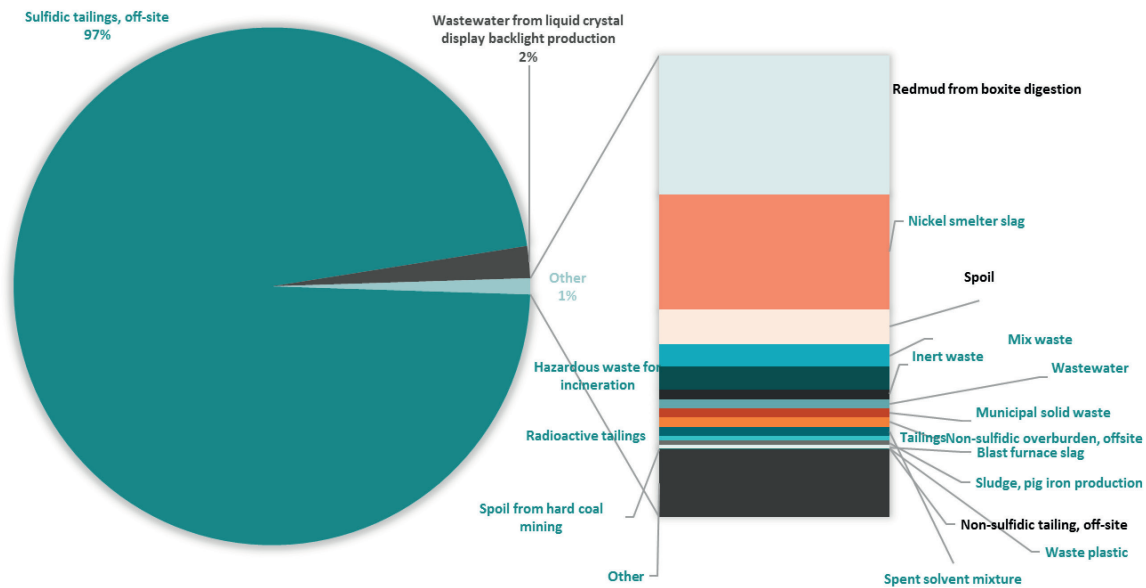


Figure 11. The different types of waste generated in smartphone production (Laurenti, Moberg et al. 2016)

significant transport demands, as its components are normally produced in different countries. The use of the product requires energy for both device charging and operating the internet infrastructure for information storage in the cloud. The end-of-life stage of a mobile phone is also energy intensive if one is to collect and sort electronic waste, transport it to recycling and dismantle and treat its various components. Understanding the complexities of such a value chain requires a life cycle approach and systematic analysis.

The environmental impacts calculated for the life cycle stages of a product or service could be expressed in different forms, depending on the goal of the study. For instance, the potential impact to climate change could be accounted for by calculating all the emissions that could cause global warming and express them as one unit – e.g. the so-called CO₂ equivalent (or carbon equivalent). The life cycle approach could also be used to calculate the so-called ecological footprint or the “human demand” of nature. This is expressed as the area of bio-productive land (in hectares) needed to provide resources for an activity (e.g. the production of a smartphone) and sustain the associated environmental damage (e.g. absorbing

all emissions). The ecological footprint can also be expressed in other units, such as water intensity, total material requirement and total amount of waste.

IVL Swedish Environmental Research Institute (IVL) prepared a study where the waste footprint was calculated for 10 consumer products. It revealed that electronic products have the highest footprint in the group in terms of waste. For instance, the life cycle of one smartphone is associated with the production of 86 kg of waste. Even higher waste footprints can be found in a laptop computer – about 1,200 kg of waste is produced over its life cycle (Figure 9).

The amount of waste and parts of the production chain generating the most waste can differ quite radically between different product groups (Figure 10). The production of input materials is often the most significant source of waste. For instance, for electronic products, metal mining and enrichment are the primary sources of waste. About 97% of all life cycle waste is generated during the production of input materials for a smartphone and this figure is even higher for a laptop (Figure 11).

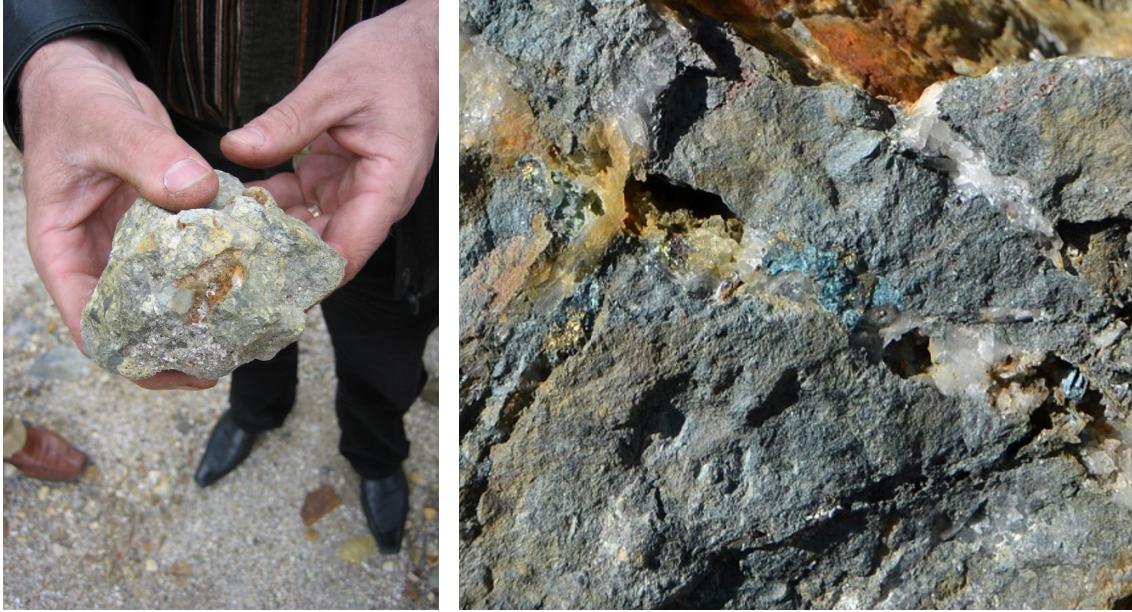


Figure 12. Rocks and ores. (Pictures by Philip Peck)

2.2. Mining

Mining and the extraction of raw materials is one of the most important sources of environmental and human health problems associated with the lifecycle of e-products. The main reasons are the large scale of operation, the proximity to the environment, and the technical and political difficulties to regulate control and abate the negative impacts from mining.

Most of the problems are caused by mining waste and its co-products, usually associated with the extraction of metals used in electronic products. Although some of the metals used in electronics are needed in very small amounts (on the scale micrograms in one smartphone), their extraction may imply significant energy intensity, chemical use and waste generation. For example, the extraction of 1 kg of raw copper generates 310 kg of mining waste, while the extraction of 1 g of gold generates 1-5 tonnes of mining waste. Additionally, 1-4 tonnes of waste could be produced during the processing of gold to make it ready for application in the electronics industry.

The extraction of rare-earth materials is usually in the form of by-products of the primary metals.

For instance, cobalt (Co) is extracted as cobaltite (CoAsS), which is a by-product from mining and the enrichment of copper or nickel. Bismuth (Bi) is a by-product from the extraction of lead, copper, tin, molybdenum and tungsten. Only very few of rare-earth materials (mainly platinum group metals) are extracted on their own as primary materials.

Although some of the mining waste can be rather inert and do not give rise to major environmental problems, much of it is either radioactive or prone to the leakage of hazardous substances, such as heavy metals like mercury, arsenic, lead, zinc and cadmium. The release of hazardous substances from mining waste is often accelerated by the chemicals used in the release of target materials. Some mining technologies, e.g. the so-called “hard rock mining”, require pulverization and the chemical treatment of rock ore⁸ into very small particles in order to get the target material. The part of the ore remaining after the target minerals are extracted is called tailing or mine dumps, which is usually in the form of a slurry with a mix of fine mineral parts, water and chemicals. The ratio of tailings and ore could be

The extraction of 1 kg of raw copper generates 310 kg of mining waste, while the extraction of 1 g of gold generates 1-5 tonnes of mining waste

⁸) The ore is rock sediment that contains sufficient element (usually metals)



Figure 13. The Bor mine in Serbia is one of the biggest copper mine in Europe and has been known as one of the environmental hotspots in Serbia for over a century. (Picture: Philip Peck)

Impacts of gold mining

In the extraction of gold using hard rock technology, the ore is first crushed, poured into pits and then sprayed with cyanide, which seeps through the ore and binds with gold. The resulting gold cyanide solution is collected at the base of the pile and then pumped to a mill where the gold and cyanide are chemically separated. The cyanide-rich material mixture is then stored in artificial ponds for reuse. Each leach takes a few months, after which the shears get a layer of fresh ore. Given the extent and duration of these operations (usually decades), the contamination of the surrounding environment with cyanide is almost inevitable. The industry has tried to replace cyanide with mercury, but this is also toxic. Both substances are extremely dangerous even in small concentrations and can cause various health issues. If not properly controlled, the heavy metals usually find their way into ecosystems and eventually into human food chains, causing serious toxic poisoning including damages to neurological and pulmonary functions, embryonic development and many other effects.

Box 2. An example of a gold mining technique and its impacts.

in the range of 90-98% (for copper) or 20-50 % for less valuable minerals. Moreover, crushing mined rocks often releases radioactive elements, asbestos-like minerals and metallic dust particles. For this reason tailings often contain some part of toxic and radioactive materials that may leak into the environment if not properly handled (MIT 2016).

The extraction of raw materials is energy and chemical intensive, which in turn can cause emissions to air and water or land pollution (Table 4). One of the highest risks to the environment from the management of tailings is related to dam failures and the release of highly acidic and toxic-containing slurries. A well-known example of environmental damage of tailings is the case of the Ok Tedi tailings dam in Papua New Guinea in operation between 1984 and 2013. The collapse of the dam released 2 billion tonnes of untreated mining waste polluted with heavy metals to several rivers. This caused toxic pollution of more than 1,500 km² of catchment area, 3,000 km² of forests and approx. 1,300 km² of agricultural lands. Experts evaluated that it would take more than 300 years to fully clean up the contamination caused by the accident.

Another significant source of environmental impact from mining is its high energy intensity. As with other heavy industries, the mining industry is highly dependent on fossil fuels, such as oil,

Risk	Affected environment	Toxic compounds
Overtopping of tailing or damage of dam (due to poor construction, overtopping, or seismic events)	Groundwater, surface water, soil	Water emissions: <ul style="list-style-type: none"> • Mostly radionuclides, as thorium and uranium • Heavy metals • Acids • Fluorides Air emissions: <ul style="list-style-type: none"> • Mostly radionuclides, as thorium and uranium • Heavy metals • HF, HCL, SO₂ etc.
Pipe leakage	Groundwater, surface water, soil	
Lack of leak-proofing in the ground of tailings	Groundwater	
Waste rock stockpiles exposed to rainwater	Groundwater, surface water, soil	
Dust from waste rock and tailings	Air and soil	
Lack of site-rehabilitation after mining operation ceases	Air and soil	
Processing without flue gas filters	Air and soil	
Processing without waste water treatment	Surface water	

Table 4. Environmental risks associated with the mining of raw materials (MIT 2016).

gas and coal, and thus produces large amounts of carbon emissions. Mining also often causes irreparable soil erosion on a large scale, the damage of which can last for years after a mine has been shut down. This includes soil erosion which disrupts natural biological cycles and the flow of nutrients, destruction of the natural habitats of native species and diminished bio-productivity of local ecosystems. Mining also requires large amounts of fresh water and generates high volumes of wastewater often contaminated with heavy metals and other toxic materials. When not managed properly it easily contaminates freshwater supplies (MIT 2016).

These problems are also often aggravated by the fact that many mining operations are located in countries with low environmental standards or poor monitoring and enforcement of environmental regulations. Some mining activities are sometimes illegal and executed in a completely uncontrolled manner. For instance, according to some estimates around 20,000 tonnes of REEs are illegally mined and exported from China. Illegal mines usually lack environmental precautions or any waste treatment, which poses significant risks to workers' health and the surrounding environment (MIT 2016).

2.3. Other environmental aspects

Energy intensive manufacturing

Besides the mining of raw materials, other production steps in the lifecycle of e-products also have significant environmental intensities. The production of many electronic components (especially semiconductors and microchips) are highly material and energy intensive. One of the main reasons is that both the components and other input materials must be very pure from contamination with other materials.

The manufacturing of semiconductors and microchips also requires clean environments, which is also highly energy intensive. For instance, the production of a Sony Xperia™ smartphone and its lifetime use in Swedish conditions (i.e. Swedish electricity and general energy mix) generate about 45 kg CO₂-equivalents, which corresponds to driving an average European car over a distance of around 300 km (Ercan 2013). The bulk of CO₂ equivalent emissions are associated with the production of integrated circuits for the phone.

The production in other countries with more dominant fossil fuel carriers would generate much higher CO₂ intensities. For instance, if the global electricity mix and all accessories are included, the total CO₂ release would increase to

E-Waste Component	Process Used	Potential Environmental Hazard
Cathode ray tubes (used in TVs, computer monitors, ATMs, video cameras and more)	Breaking and removal of yoke followed by dumping	Lead, barium and other heavy metals leaching into groundwater and release of toxic phosphor
Printed circuit board	De-soldering and removal of computer chips; open burning and acid baths to remove metals after chips are removed	Air emissions and discharge into rivers of glass dust, tin, lead, brominated dioxin, beryllium cadmium, and mercury
Chips and other gold-plated components	Chemical stripping using nitric and hydrochloric acid and burning of chips	Polycyclic Aromatic Hydrocarbons (PAHs), heavy metals, brominated flame retardants discharged directly into rivers acidifying fish and flora. Tin and lead contamination of surface and groundwater. Air emissions of brominated dioxins, heavy metals, and PAHs
Plastics from printers, keyboards, monitors, etc.	Shredding and low temp melting to be reused	Emissions of brominated dioxins, heavy metals, and hydrocarbons
Computer wires	Open burning and stripping to remove copper	PAHs released into air, water, and soil.

Table 5. Examples of illegal recycling practices of e-waste in India at its environmental risks (Wath, Dutt et al. 2011).

117 kg CO₂ for the 3 year life cycle period of the phone (Ercan 2013).

Improper disposal of e-waste

Some precious and other valuable materials are present in e-waste, which makes it attractive for recyclers. Unfortunately, acquiring these materials is labour-intensive and often does not make sense in countries with high labour costs. For this reason, e-waste is often subject to illegal shipments from developed countries to the

developing world for recycling. Here e-waste is often dismantled and semi-recycled illegally using low-tech solutions with poor or no protection from the associated health risks and environmental pollution. Some of the most common illegal practices and the associated risks are presented in Table 5. Many hazardous and toxic materials are released during improper dismantling or recycling operations, which inevitably enter into food chains and pose risks to human health.

3. SOCIAL ASPECTS OF E-WASTE AND RAW MATERIALS

Along with the environmental issues associated with the lifecycle of critical materials and e-waste, there are also many social issues, especially related to the mining of raw materials, illegal shipments and improper recycling of e-waste.

Mining the specialty materials used in electronic products often takes place in politically unstable regions and conflict-prone economically underdeveloped countries with weak regulatory systems, ineffective governance structures and inadequate technological means to ensure the sustainable extraction of natural resources (MIT 2016). Local governments, leasing out the exploitation rights to commercial (usually foreign) mining companies, sometimes trade sustainable long-term visions for short-term profits. The lessors that exploit natural resources are primarily profit-driven and may take advantage of ineffective regulations and weak enforcement mechanisms that eventually hurts both the environment

and the local communities. Commercial actors might choose to follow less stringent work safety procedures and neglect environmental protection standards. Poor regulations and often absent trade unions result in unfair working conditions and exploitation of the labor force. Therefore, although some countries are rich in natural resources, the general population may fail to reap the potential economic and social benefits of its exploitation (see examples in Box. 3 and Box. 4).

The social and environmental issues associated with the mining of rare earth metals in developing countries are complex and represent not only a local problem. They also indirectly influence global markets in terms of final material prices and the future availability of resources. Technologically sub-optimal and polluting mining operations are also economically inefficient. Mineral extraction at poor yields depletes the available resources, which in the light of growing



Figure 14. Coltan mining in the Congo is often controlled by armed groups and performed with primitive technologies (Source: Harneis 2007).

The Democratic Republic of the Congo (DRC) could serve as an example of social issues caused by the mining of critical materials for the electronics sector. Coltan (columbite-tantalite) is a metal ore-containing the minerals of two critical elements - niobium and tantalum, which are critical for producing certain electronic products and their components (e.g. batteries). DRC possesses about half of the world's known coltan reserves. At the same time, DRC is one of the most politically unstable regions in the world struggling with several economic challenges. This results in underdeveloped industrial infrastructures, low levels of foreign investment and poor governance structures.

Most of the coltan in the DRC is "mined" using primitive labor-intensive technologies, such as manual mining and water stream beds similar to those used during the American gold rush. While some studies suggest that miners can earn more than \$50 per week (which is up to 20 times more than the average daily income in the country), the labor force is often subject to exploitation by various armed groups. These groups reportedly often resolve to violence including terror, rape and even murder to control the access over mining operations and subjugate the laborers. At several mining sites there have been reports of illegal exploitation of workers under bad conditions and the use of child labor. The uncontrolled and unregulated mining operations results in significant environmental damage such as soil erosion, water pollution and the destruction of natural habitats, which also affects endangered species.

There has been some international response to these problems including efforts to boycott some mineral resources from the DRC, which is thought to reduce the revenue flows to illegal operations and the armed groups. However, the positive effects of such actions are either ineffective or are yet to be seen, as illegal actors are finding ways to fraudulently export mineral resources via other neighboring countries, such as Uganda, Burundi and Rwanda.

Box 3. *Example of social issues related to rare earth metals extraction in Congo (MIT 2016).*

demand and limited new discoveries threaten the long-term security of supply and result in sometimes significant price inflation. Poorly managed facilities also leave costly economic footprints.

For instance, after the shutdown of the Malaysian plant in 1994, the Mitsubishi Corporation has since spent \$100 million on environmental clean-ups (Long J.T., 2012), while the economy of Bukit Merah may take several decades to fully recover (MIT 2016).

However, the human costs of environmental mismanagement are much harder to quantify in monetary terms. In the case of the Mitsubishi mine in Malaysia, local public health officials reported at least 11 deaths from blood poisoning, leukemia or brain cancer clearly linked to the radioactive waste pollution produced since 1994, and hundreds of local inhabitants have become sick or suffered from birth defects (Jegathesan 2012). In the case of Congo, REE mining often puts money directly in the pockets of brutal militias fueling one of the most bloody and continuous conflicts since World War II. In 2007, when the last serious assessment was made, the Congo civil war had claimed 5.4 million lives, and 45,000 more were dying monthly as a direct result of the conflict (2010). Although the mining of coltan may only fund part of the war, its role should not be underestimated (MIT 2016).

Another crucial social issue is related to e-waste. Rapid technological development and falling prices of electronic hardware result in increasing consumption of e-products and high volumes of e-waste around the globe. As discarded electronic products still have some economic value in terms of re-usability or valuable materials, a large volume is shipped from rich parts of the world to developing countries in Asia and Africa for re-use or processing and recycling. A large part of these shipments is illegal.

International actions and regulations include the Basel Convention⁹, which concerns the illegal shipment and disposal of hazardous wastes, and was launched in 1992 to restrict the movement of hazardous waste materials. However, they remain ineffective. For instance, it is estimated that approx. 2Mt of e-waste leaves Europe illegally every year. According to some studies, Asia is the main destination for e-waste from North America and Europe. Around 90% of these exports (or 8Mt annually) are being shipped to China (see Box

9) The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. It is an international treaty designed to reduce the movements of hazardous waste between nations, specifically to prevent transfer of hazardous waste from developed to less developed countries. Although many states have signed the Convention, some countries (e.g. the U.S.) have not ratified it. See: <http://www.basel.int>.



Figure 15. Children in developing countries are the most vulnerable to hazardous chemicals from e-waste imported from western countries (Source: Flickr 2009).

5 and Figure 15) despite the fact that China has banned the imports of e-waste since 2000. One of the persistent issues is that e-waste products are often classified as “reusable”, but in practice they are no longer functional and the main purpose of their shipment is to avoid high treatment and management costs in the countries of origin. In the destination countries e-waste is often re-processed and recycled in an illegal and often improper manner using low-tech approaches with low yields of material extraction and hazardous practices. For instance, the dismantling and extraction of metals often involve the burning of cables and acid leaching mainly targeting valuable materials, such as gold, silver, copper or other bulk metals. This results that hazardous elements (such as heavy metals, dioxins and other toxins) being released into the local environment causing harm to human health and to the environment. In many cases the recovery operations involve child labor exposing them to multiple hazards. The processed e-waste is then often discarded in illegal dumpsites on-site further polluting the local environment.

The city of Guiyu in China with its 5,000 workshops and 100,000 informal workers has become the largest e-waste disposal site in the world. At the site about 15,000 tons of e-wastes are recycled on a daily basis involving more than 80% of the local workforce. The working conditions are notoriously poor leading to very high exposures to dioxin and heavy metal poisoning and resulting in extreme rates of miscarriages. It has also been found that two thirds of children have very high levels of lead in their blood.

Box 5. An example of the largest e-waste disposal site in the world.

10) Greenpeace, URL: <http://www.greenpeace.org/eastasia/campaigns/toxics/problems/e-waste/guiyu/>

4. WHAT TO DO? CIRCULAR ECONOMY

Today, the concept of the so-called “circular economy” is increasingly visible in the media and in the political discourse as a strategy to improve resource efficiency and reduce the environmental footprints of consumption. The idea of the circular economy is not new, as it traces its origins to the 1960s and in particular Kenneth Boulding’s essay: “The Economics of the Coming Spaceship Earth” (Kenneth E. Boulding 1966). The concept was originally inspired by nature’s cycles of nutrients where different species co-exist in symbiotic relationships with each other. In addition, the circular economy is also inspired by the ideas found in industrial ecology, a relatively new branch of science that focuses on understanding and rationalizing the interaction between the bio-sphere and anthroposphere (Geissdoerfer, 2017; Allwood, 2014; Ellen MacArthur Foundation, 2017).

Indeed, Earth can be considered as a closed system from the material point of view where waste and emissions do not really exist, as the waste of one species becomes food for another, a relationship that cascades through multiple cycles along ecosystem and food chains. For instance, when a

plant or an animal dies, it becomes food for other organisms, such as worms and bacteria, which decompose materials into suitable nutrients to other plants and animals.

Our society, however, has adapted a linear “take, make, use and dispose” approach to its interaction with the environment. Today, we extract raw materials, produce many different products cheaply, use and then discard them often with much of the remaining functionality remaining. Much of the discarded products end up in landfills where their value is lost, and the embedded materials eventually exert environmental impacts.

The aim of the circular economy concept is to mimic natural processes and strive towards a zero-waste economy, where waste from one economic activity could be turned into inputs to other activities. The economy should therefore become a regenerative system that cycles natural resources so that waste, emissions and energy leakages could be minimized as much as possible. Circular economy approaches include, “slowing”, “narrowing” and “closing” material and energy loops. This implies many strategies that extend the lifetime of products through rational design,

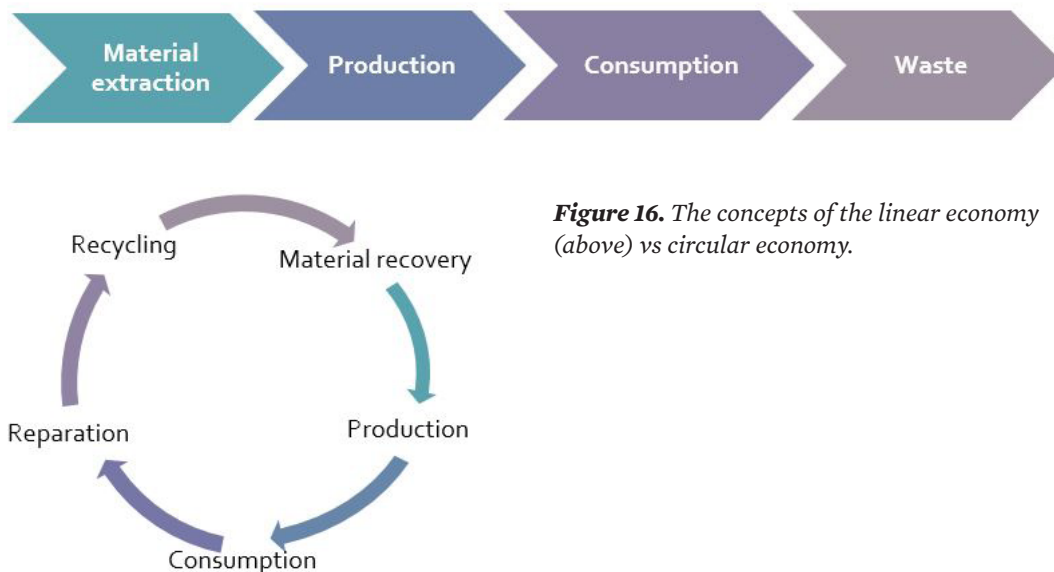


Figure 16. The concepts of the linear economy (above) vs circular economy.

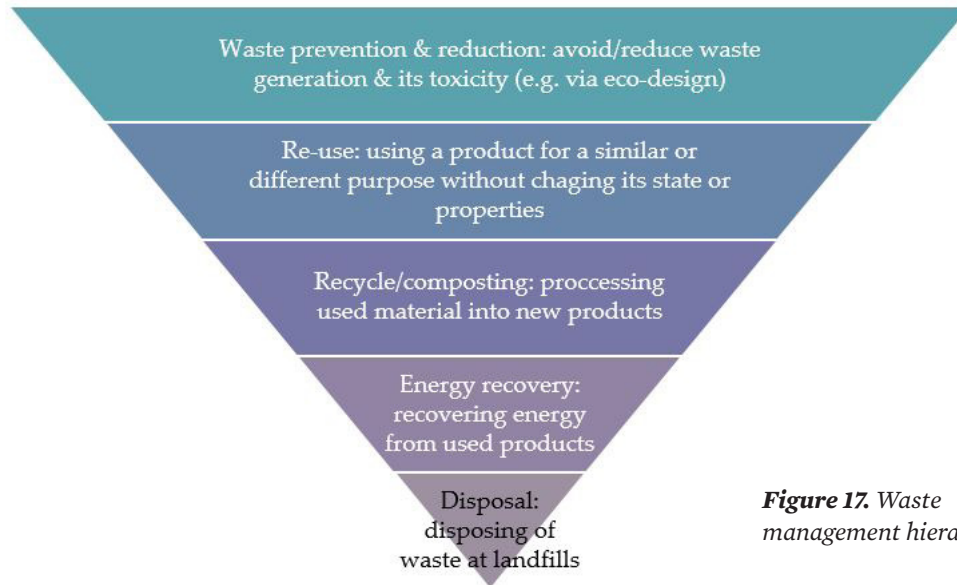


Figure 17. Waste management hierarchy.

conservative consumption and smart maintenance, re-use, recycling and recovery. Products should be designed for long life, easy use and maintenance as well as upgradability, ease of disassembly and recycling. A good strategy is to shift to biological materials that can be regenerated and easily recovered through composting (for nutrient recovery) or anaerobic digestions (for energy recovery). Circular economy also implies that companies, organizations and the society at large should adapt circular business models that make economic sense and encourage economic interest in circling materials as much as possible (Geissdoerfer, 2017).

The concept of circular economy distinguishes technical and biological (or anthropogenic) cycles. In biological cycles food and bio-based materials (e.g. cotton, wood) can feed back into use through processes like composting and anaerobic digestion. These cycles regenerate and feed living systems, such as soil, which provide renewable resources for the economy. Technical cycles recover and restore products, components, and materials through technical processes like reuse, repair, remanufacturing and (in the last resort) recycling.

4.1. The waste management hierarchy

The focus of the circular economy is not only on smart production systems but also on rational waste management strategies. All EU countries have a common waste management strategy and guidelines on how to decrease the environmental impact of waste. It is called the “waste management hierarchy” (Figure 17).

The waste management hierarchy is as a strategy or guiding principle for manufacturers, governmental organizations, consumers and other actors in society on how to prioritize waste management approaches to decrease its environmental impacts and increase circularity.

- **Waste prevention and minimization** is the first step of the hierarchy which suggests that waste should be avoided in the first place to maximize the positive environmental outcomes. It addresses the need to both reduce the amount of waste and its toxicity. This could be achieved by, for example, producers designing better quality products with longer lifespans, businesses creating new value-added offers for consumers (e.g. offering products for consumers to rent instead of own) and consumers changing their consumption patterns by prioritizing sufficiency, sharing products, and substituting products for services.

- **Re-use** is the second-best environmental alternative for waste management. It means to use the products for the same or different purposes without changing its primary properties. Examples of re-use are buying second-hand products instead of new products and sharing products with others. Re-use also implies more focus on product repair, maintenance and upgradability. This in-turn demands re-thinking product design for longevity and maintainability. Sometimes re-use is possible for the product’s components if not the product as a whole.

- **Recycling** is the suggested strategy when it is no longer possible or feasible to re-use the product or its parts. It means that all waste should be material-recycled as much as possible, since

substituting virgin raw materials by recycled materials often implies much greater environmental efficiency.

● **Energy recovery** – can also be regarded as low-grade recycling, where the energy content of the product is recycled instead of the material value. It should be applied when the material in waste can no longer be recycled from a technical or economic point of view, and the most feasible option is the recovery of its embedded energy. The environmental benefits of energy recovery depend on the type of waste material and the efficiency of energy recovery plants (incinerators). As a rule of thumb, the highest environmental benefits are achieved in combined heat and power (co-generation) plants producing electricity and heat for district heating or industrial uses.

● **Landfilling** is the least favorable waste management option for materials that cannot be re-used, recycled or recovered for its energy from the technical and economic points of view. Landfills could cause serious environmental impacts including global warming emissions and emissions of toxic leachate into groundwater, as well as health impacts through exposure to toxic emissions and other contagious diseases. Under the waste management hierarchy, landfilling should only take place on properly designed and monitored sites where the formation of methane gas is prevented and controlled by flaring and leachate treatment is applied.

4.2. What is the state of e-waste management today?

E-waste is the fastest growing waste stream in the EU and globally. A recent study estimated that more than 44.7 million tonnes or on average 6.1 kg/capita of e-waste was generated globally in 2016, an increase from 5.8 kg/capita in 2014. This corresponds to the weight of about 4,500 Eiffel Towers! By 2021 the annual generation of e-waste is expected to increase to 52.2 million tonnes, or 6.8 kg/capita (Baldé, Forti et al. 2017).

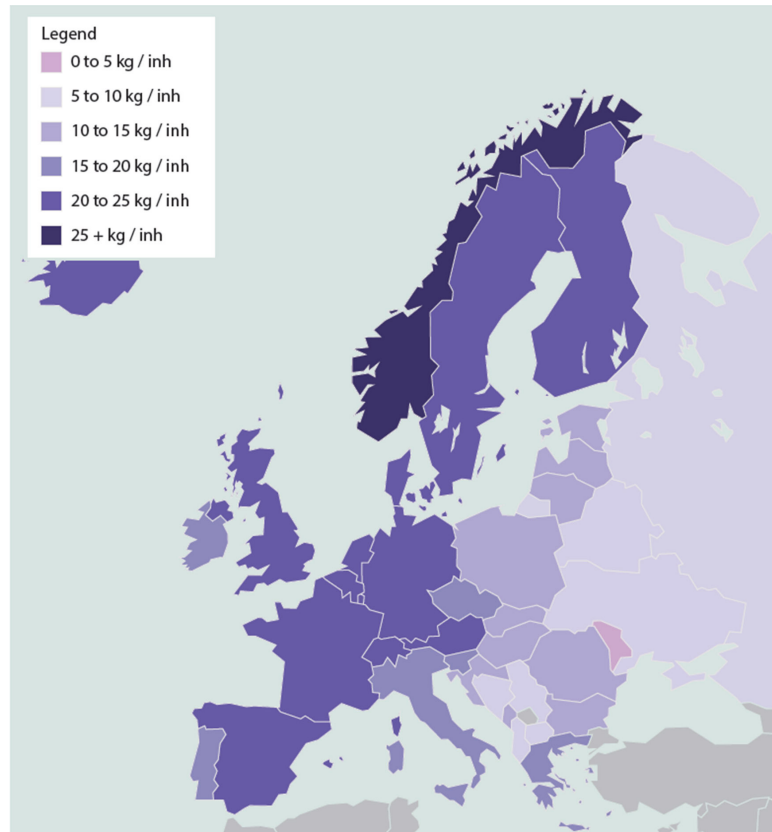


Figure 18. E-waste generation in the EU (Baldé, Forti et al. 2017)

In 2016, only 20% (or 8.9 million tonnes) of the total 44.7 Mt of e-waste have been documented as collected and recycled in a “proper” way (i.e. according to all existing regulations) in high income countries with reasonably developed waste collection and sourcing systems. An estimated 4% are thrown into residual waste which is likely to be incinerated or landfilled. The fate of the remaining 76% (34.1 Mt) is actually unclear. Most of it is likely illegally dumped, but it is more likely that most of it is traded internationally and destined for “recycling” in developing countries where manual labor is cheaper and environmental and work protection standards are relaxed (Baldé, Forti et al. 2017).

In the EU the amount of e-waste generated is also growing rapidly, from an estimated 9 million tonnes in 2012 to 12.3 Mt in 2016 (16.6 kg/capita), which is expected to grow to over 12 million tonnes by 2020. At present, only approx. 30% of the e-waste generated in the EU is officially reported as being treated in compliance with existing European regulations (EC 2018). Among the members of the European Economic Cooperation (EEC), Norway has the highest per capita generation of e-waste – approx. 28.5 kg/capita, followed by Great Britain and Denmark

(each 24.9 kg/capita). The per capita generation in Sweden, Italy, Ireland and Spain is respectively 21.5, 18.9, 19.9 and 20.1 kg (all 2016 data) (Baldé, Forti et al. 2017).

E-waste management in the EU is regulated by the so-called WEEE directive (2012/19/EU). It regulates the collection, recycling and recovery of e-waste by prescribing waste management practices and defining the roles of different stakeholders. The Directive's targets for collection of e-waste placed on the European market in 2016 was 45%, which will increase to 65% by 2019. The best EU countries in e-waste collection are Switzerland (74% of the waste generated), Norway (74%), Sweden (69%) and Finland and Ireland (each 55%) (Baldé, Forti et al. 2017).

Reaching the ambitious targets is challenging especially in terms of recycling rates. Today the average e-waste recycling rate is around 35-37%, which has been stagnant since 2009 (Baldé, Forti et al. 2017). Although the European average e-waste collection rate is the highest in the world, its collection and recycling performance is highly heterogenous across member states. Countries like Switzerland, Norway, Sweden, Finland, Germany and Italy lead in terms of recycling rates, but even in these countries the main challenge is reaching higher recycling rates

for smaller electronic components. Recyclers in most European countries primarily target e-waste components which yield as many materials as possible with little dismantling efforts and lower labor costs (e.g. computer casings and power units). This means that materials such as copper, aluminum and plastic in e-waste are typically recycled first. Smaller parts with electronic components are usually too expensive to dismantle and recycle due to high labor costs and low volumes, preventing the economy from reaching scale. Smaller electronic components are usually shredded and incinerated or landfilled. Moreover, it is not uncommon that waste electronic parts are shipped illegally to developing countries for un-controlled recycling which poses high risks to workers' health and generates serious environmental pollution.

This also implies that the recycling of critical materials present in e-waste is very low. Figure 19 presents global recycling rates of 60 metals (Graedel et al. 2011). Although the recycling rates of precious metals such as platinum, palladium, gold, silver and cobalt are as high as 50% or more, many other metals (especially the rare earths such as lanthanides, scandium, yttrium, tantalum, gallium and indium) are recycled at less than 1%.

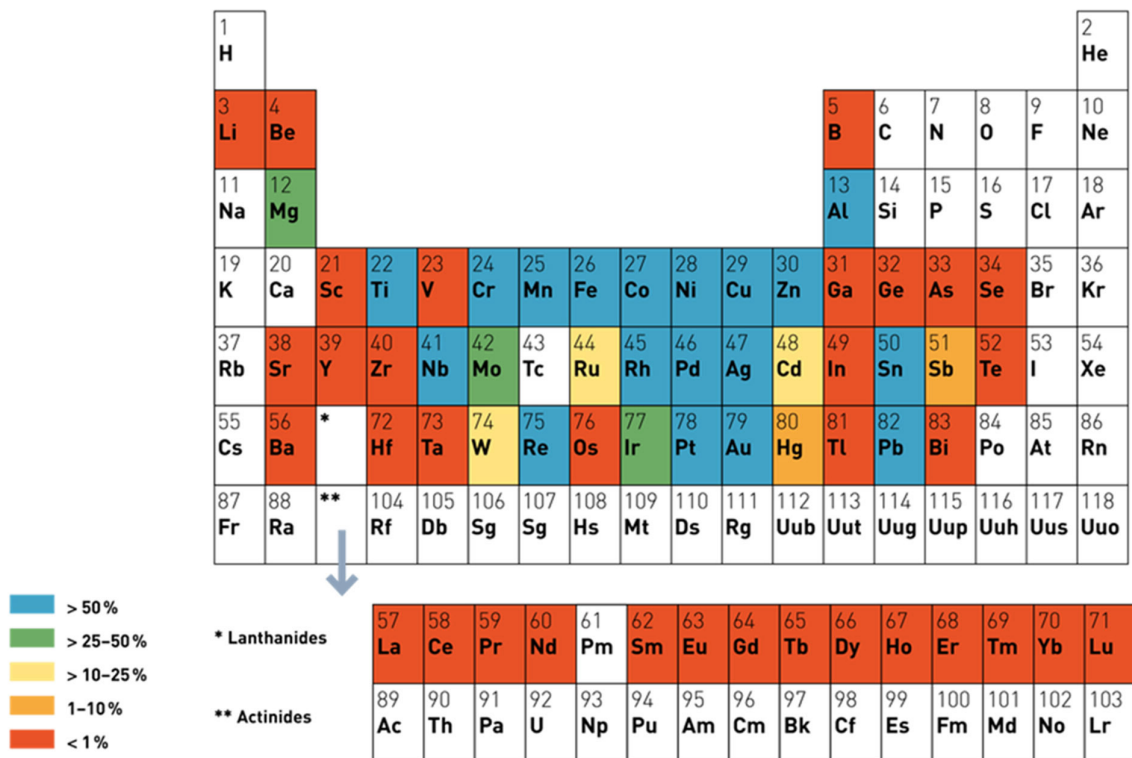


Figure 19. Global recycling rate of 60 metals (Graedel et al. 2011).

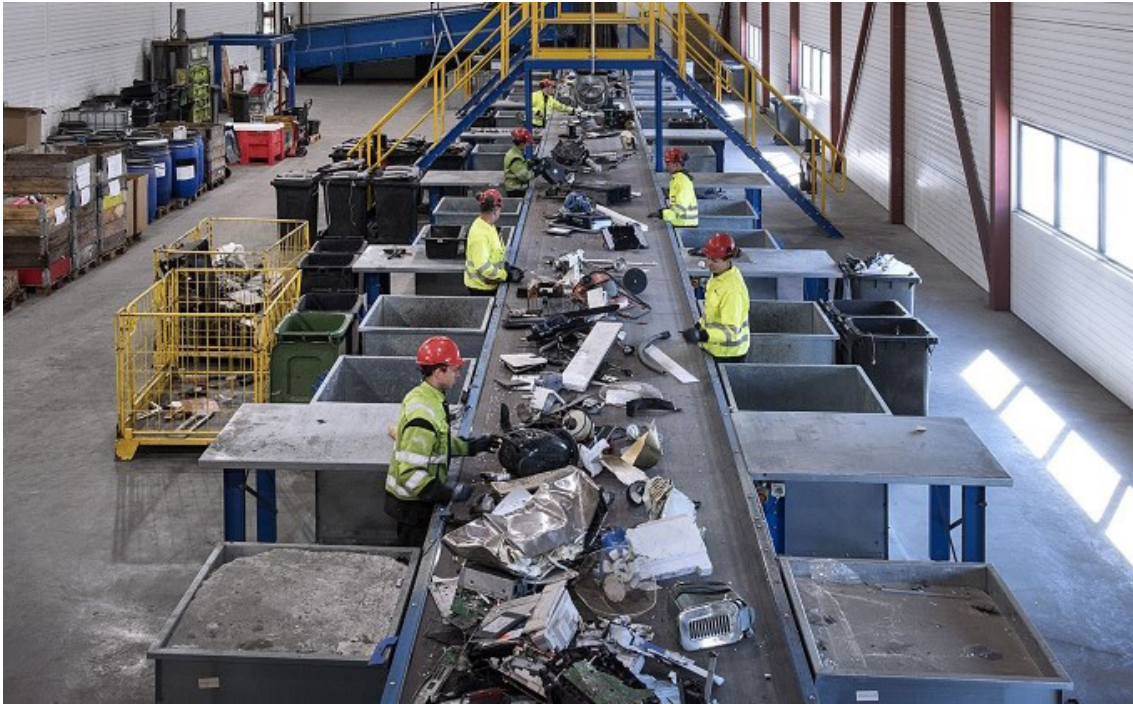


Figure 20. E-waste pre-processing in REVAC. (Source: REVAC AS 2019, Norway)

4.3. General overview of the recycling process

The formal e-waste recycling industry usually consists of 3 main phases: collection, pre-processing and end-processing. Although each of phases could be performed by a single company, it is common that several specialized companies are involved in this chain.

I. Collection. Collection is very important to secure cost-effectiveness in recycling. The collected e-waste should be free from other materials and preferably include uniform types of e-waste. This phase is less dependent on technical solutions (type of collection transport or type of containers) and the available infrastructure, but is highly influenced by socio-economic factors, such as households' environmental awareness, waste management knowledge and engagement in exercising their role in sorting different waste fractions. High engagement of waste producers is very important to secure high recycling rates as well. Collection efficiency is the weakest link in e-waste recycling. Even at very high recycling efficiencies (high yields), low collection rates will significantly influence the total yield of recovered materials as the share of total e-waste generated. For instance, even a rather high collection rate of e-waste in Austria (49% in 2015) with its pre-processing efficiency of 75% and end-processing efficiency of 99% has resulted in a total e-waste

material recovery rate of only 38%.

II. Pre-processing. The second phase is preparation for recycling or pre-processing. It usually includes 3 steps: (1) de-pollution, (2) mechanical treatment and (3) sorting. Two main technologies are practiced for de-pollution in Europe - manual dismantling where valuable and hazardous components (e.g. batteries) are sorted out manually at fairly high rates, and mechanical dismantling (by crushing and shredding) followed by manual sorting of hazardous and valuable materials on conveyor belts.

The de-pollution process includes one or several shredding processes aimed at reducing the size of devices and elimination of potentially hazardous components. Once reduced in size the shredded components in e-waste undergo mechanical sorting, where different sorting technologies are applied. They can vary depending on input and target materials, legal requirements, and other technological and economic factors. Recyclers often are mostly interested in the bulk metals such as iron and copper. Ferrous metals can be sorted using magnets. Non-ferrous metals (e.g. aluminium or copper) can be sorted by applying electro-magnetic fields, the so-called Eddy-Current technology. Plastics, which represent a very large share of materials by weight, are sorted manually or using mechanised sorting techniques, such as optical spectrometry and floating technologies. In the former, different

plastic types are mechanically separated by colour using high-tech optical recognition technologies. In the latter the plastics are sorted by blowing air or in liquid batches according to their stoichiometric weights. Regardless of the approach and the chosen technology, in the pre-processing stage 4 groups of materials are extracted: (i) hazardous materials (e.g. batteries), (ii) valuable components, which could be re-used/re-sold on the market after dismantling, (iii) valuable recyclable materials (copper, aluminium, plastics) that will be sold for further material recovery, and (iv) residues - non-hazardous materials (ceramics, some plastics etc.), that are not suitable for recycling. This fraction is likely to be disposed of in landfills or incinerated.

III. End-processing. This phase is rather technologically intensive and aims to recover metals and plastics. Today metal recovery is usually done by pyrometallurgical processing and hydrometallurgical processing (to a lower extent) (Cui and Zhang, 2008). The magnet-sorted ferrous metals are directed to steel smelters to recover iron. The Eddy-current sorted non-ferrous metals, such as aluminum-rich fractions, are sent to aluminum smelters. Components rich with copper materials (e.g. wires) and hazardous components (e.g. capacitors, PCBs, switches) are channeled to integrated smelters, which can recover up to 30 different metallic fractions. At the same time, the emission of hazardous substances is controlled by advanced filtration systems (Hagelken and Corti, 2010). However, the pyrometallurgical processing is highly capital-intensive, while the hydrometallurgical processing involves the use of strong acids and can have a significant environmental impact. Other emerging technologies, such as bio-metallurgy and electro-metallurgy can address some of these issues, but currently they still lack cost-efficiency and sufficient installed capacity.

4.4. Advantages of e-waste recycling and urban mining

Since only 15-20% of global e-waste is recycled annually, and the demand for materials is growing, recycling and urban mining are gradually becoming material sources of interest. The term “urban mining” refers to the collection and recycling of raw material from used products, buildings and waste in general. The term “urban mines” emerged because targeted materials are often located in urban areas. Urban mining from e-products usually refers to material recovery of metals from e-waste (including post-consumer electronic products), metals embedded in buildings (e.g. cables) and deposits after waste treat-

ment (e.g. landfills, also called “landfill mining”). Landfill mining refers to extracting valuable materials from concentrated e-waste fractions in landfills. The term urban mining of e-waste is also often associated with the collection and recovery of critical metals.

The main benefits of urban mining and recycling e-waste are resource conservation and the reduction of environmental impacts from primary extraction and toxic pollution from industrial operations. In addition, an increased diversion of e-waste from landfilling reduces the demand for landfills and incineration, which also generates capital savings. A reduction of toxic releases from e-waste in landfills also decreases pressure on sensitive ecosystems and risks of negative social consequences from illegal waste management in third countries (Litchfield, Lowry et al. 2018).

Moving toward the circular economy can also deliver great economic benefits. Urban mining can deliver significant economic gains and employment opportunities in recycling and metallurgical industries. It is well known that recycling can create so called “green jobs” in the sector in a much higher range than landfilling or incineration. Urban mining in the EU provides an alternative way for local companies to access valuable materials and decreases their criticality and dependency on imports from politically unstable regions. Only a few of the rare metals are directly available from primary sources within the EU today. However, the manufacture of e-appliances and reprocessing of materials into new products are mostly done in other parts of the world, often under low working standards. It is estimated that rare metals embedded in global e-waste have a net value of 55 million EUR (Table 1) (Baldé, Forti et al. 2017).

Material	Amount (kt)	Value (M EUR)
Iron (Fe)	16,283	3,582
Copper (Cu)	2,164	9,524
Aluminum (Al)	2,472	3,585
Silver (Ag)	1,6	884
Gold (Au)	0,5	18,840
Pd	0,2	3,369
Plastics	12,230	15,043

Table 6. Examples of amounts and values of some materials in e-waste generated globally (Baldé, 2017).

4.5. Challenges to the circular economy

4.5.1. Economic challenges of e-waste recycling

The economic feasibility of material recycling from e-waste (especially rare metals) is typically determined by the level of technology and the costs of waste collection and logistics. Many precious metals such as gold and platinum are often present in e-waste in sufficiently large quantities to make their recycling economically viable. The recycling of metals, especially rare elements, is more complicated. In Europe, the largest commercially viable rare metals recycler is Umicore Ltd. in Hoboken (Belgium), which is capable of recycling many precious rare metals from diverse waste sources including e-waste. Its estimated annual recovery rate of 70,000 t of metals corresponds to around 1M t of avoided CO₂ emissions for the production of metals from primary sources (Hagelüken 2010). The commercial advantage of e-waste recycling is the fact that the concentration of valuable materials is up to 50 times higher than in minerals and natural ores. For instance, approx. 1 t of modern smartphones can yield about 300 g of gold.¹¹ Extracting this amount of gold from natural sources may require mining and processing of 300-1,500 tonnes of gold-rich primary ore. In most cases, the collection of post-consumer waste in urban mining may require significantly less energy and produce much less waste.

Unfortunately, Umicore and its recycling site in Hoboken is the only entity to-date that has demonstrated large scale economic viability in broad range metals recycling from electronic waste in Europe. Advanced technologies and sufficiently large volumes of e-waste are important factors for its economic viability. Other smelters, such as Boliden in Sweden and others in Germany, Italy and France can only economically extract a limited range of metals, mainly non-ferrous and precious metals. Higher collection rates of e-waste and increasing raw material prices may make more companies commercially viable in the future. With increased demand for critical materials and increased collection of end products, the number of recyclers will likely also increase.

4.5.2. Environmental and technical issues

To date, the recycling of e-waste has mainly focused on extracting high-volume metals: materials such as steel, aluminum, copper, glass and plastics. However, diverse e-products contain significant amounts of critical metals and rare



earth metals (see chapter 1.2). Expanding the focus of e-waste recycling from bulk materials (metals and plastics) to the recovery of critical and rare earth metals could potentially lead to substantial economic and environmental benefits. However, recycling of these materials, especially critical metals, is not easy. According to some studies urban mining of rare metals can recycle, globally, less than 1% of their embedded content (Chancerel 2010).

This is determined by several factors. Electronic products are characteristically complex and consist of a wide variety of different materials and components. Despite the rapidly growing amounts of electronic products (TVs, tables, laptops or monitors) sold on the global market, the concentrations of many materials (e.g. gold and rare earth metals) per unit of product is rapidly declining. Although the trend is generally bene-

11) Source: <https://www.recupel.be/en/why-recycle/7-reasons-why-urban-mining-is-overtaking-classical-mining/#>

ficial, as less materials are required and “more is done with less”, it also means that recovery of a more diluted material content becomes ever more challenging (Baldé, Forti et al. 2017).

Urban mining of critical rare earth metals from e-waste depends on the type of devices and the potential value of the embedded raw materials. Precious metals in printed circuit boards are generally recovered due to their high economic value and positive relationship to recovery costs. At the same time, the recycling of other materials such as gallium, germanium, indium, and rare earth metals is challenging as they are dispersed in products and require high volumes of waste in one place to make recycling more economically efficient (Mathieux, Ardenne et al. 2017). Moreover, there are several technical problems associated with the recovery and purification of specific metals from very low quantities in e-waste.

One of the greatest challenges related to e-waste recycling is their geographical dispersion and illegal ways of recycling. A very large share of e-waste never enters formal recycling systems. Much of the e-waste is transported from the EU to developing countries, where extraction of metals is made using primitive technologies with low efficiency and no environmental or human health protection measures in place (see chapter 3). Illegal exports are probably the biggest threat for achieving high e-waste recycling rates. Moreover, part of the e-waste is not sorted out and ends up in the residual waste flow and goes either to incineration or landfilling depending on the waste management system of the EU country in question (Baxter, Stensgård et al. 2015). To increase e-waste recycling requires higher environmental of households and well-functioning waste collection system.

Growing consumerism is an overarching environmental problem for all waste materials. The global middle-class and their income are increasing, and this demographic group often prefers to purchase new products and devices, as this is often associated with a perceived status symbol and provides social recognition (Baldé, Forti et al. 2017). Rapid technology cycles in electronic products induce excessive consumption because most of the electronic products are discarded before their technological lifetime. Consumers have developed a habit of replacing their devices

with ever new state-of-the-art product versions at ever decreasing costs. For instance, a smartphone technically has a life span of 4 or sometimes even 7 years, but the average use time of smartphones in Europe does not last longer than 1.5-2 years. Usually, the lifetime of smartphones is determined by the duration of the contract with telecom providers.

Similar patterns are observed with other electronic products such as laptops, PCs, TV sets and routers. It is also not uncommon to keep some “outdated” devices for some time before discarding them. For instance, a study in Norway showed approx. 10 million of mobile phones are kept in households without being used. About 60% of Norwegians own more than 2 phones that are not in use (Baxter, Wahlstrom et al.

2015). Although idle devices do not cause much harm to the environment, they represent a lost opportunity of re-selling or donation to offset the impacts of producing new devices. Moreover, idle devices represent an underutilized resource stock that could be turned into useful materials for the industry.

It is important that the whole system and all actors from the product life cycle are involved in circular solutions. The products should be designed for longevity, easy upgrades, maintenance and repair as well as disassembly for recycling. Consumers should also make informed decisions when purchasing electronic products by primarily adopting sufficiency principles, potential product sharing, send-hand marketing or donations as well as proper sorting and disposal habits. Government actors should support both producers and consumers in these strategies by creating favorable conditions and policy support. Good policies are also needed to facilitate the creation of an infrastructure that encourages the re-use, repair and material recovery of valuable materials. Local authorities play a role in developing adequate systems for collection and management of e-waste. Spreading good practice examples is an important educational measure.

It is important that all parts of the system work properly, which is only possible when different actors act in a responsible way. The main actors and their responsibilities are described below.

A study in Norway showed approx. 10 million of mobile phones are kept in households without being used

5. ROLES AND RESPONSIBILITIES OF VARIOUS ACTORS

Considering that a product's environmental impact is caused throughout the product's entire life cycle, from the acquisition of raw material and production to consumption and waste management, the involvement of all actors in mitigating these environmental impacts is vital. For example, a manufacturer can optimize the manufacturing process so that as little energy and material is used as possible, whilst the consumer has the power to choose what product to purchase (or not to purchase) and thus use her or his consumer power. In this section the roles and responsibilities of these different actors are described.

5.1. Consumers

As all production is caused by the demand of consumers, it is not of little importance what (and if!) the consumer decides to purchase. This goes for both individual consumers and consumers such as authorities (e.g. schools) and companies. The consumption of home electronics is increasing, and the environmental impact of these products are greater than the environmental impacts of many other products. It is therefore important to think about the alternatives before buying new products (Hallå Konsument 2017). Some are presented in Box 6.

If electronic or electric waste is discarded, it should be turned in at recycling stations so that the material can be put to use again. If the product is functional, or even if only small adjustments need to be made for it to be functional, it should be turned in to a refurbishment company or secondhand stores. It is also possible to turn in e-waste to retailers who are obliged to collect it.

Batteries contain hazardous substances such as mercury, cadmium and lead and can do great harm if they end up in the natural environment. Small batteries can be turned in at battery collection boxes that are placed in numerous places in connection to recycling stations, recycling rooms in apartment buildings and even at grocery shops.

Today many companies offer leasing contracts for computers (among other products). This business model decreases the company's need for

- Most importantly, think about what your needs and purposes are with the new product. Are there alternative ways to meet that need/purpose? Is it possible to borrow, buy the product from a secondhand source or repair your current device instead?
- If you do decide to buy a new product, choose a product with a long lifespan so that you may use the same device for a longer time. This decreases the total environmental impact and the use of raw materials.
- If the product you have purchased breaks, the company you bought it from is obliged to troubleshoot the product and fix the problem or replace the device with a new one if the problem is caused by a manufacturing defect.
- Remember you have the right to make a complaint regarding the product within three years from purchase.

Box 6. *What to think about before purchasing new electric or electronic equipment.*

the consumer to purchase new products in order to be economically viable. Instead, the function of the product is offered, and this creates incentives for the company to build products that have a longer use life as it is in their economic interest.

Another alternative is to purchase secondhand products. Depending on the company, these products can be offered with a guarantee and the consumer does not have to worry about whether the product will function properly or not. These companies refurbish secondhand computers and upgrade them to hold good quality. Many of the refurbishment companies also guarantee that information on the device is properly deleted before selling the product on the secondhand market, an issue that many consumers are typically concerned with.

Many households have a lot of equipment lying around that they do not use. As electric and electronic devices are upgraded constantly they become outdated fast. Products that are not used should be turned in to a proper collector as described above so that the product and material

might be of use again, which helps in decreasing the use of raw materials and mitigating adverse environmental impacts.

5.2. Producers

The producers of electric and electronic products can also influence their products' environmental impact with various measures and the consumer can pressure the producers with the choices they make when making consumption choices. Producers are responsible for taking care of e-waste and treat it in the most environmentally friendly way (Swedish EPA 2018):

A Directive is a form of legislation “directed” at Member States in the EU that defines objectives or policies that need to be attained (European Law Monitor 2018). Under the WEEE Directive, EU Member States are obliged to take back and recycle electric and electronic end products. The same is true for batteries under the EU Battery Directive (WEEE Europe 2018). This is called Producer Responsibility and it is a policy instrument designed to reach European environmental goals by mitigating the products' environmental impact. The idea is to motivate producers to develop products that use less raw material, products that are easier to recycle and that do not contain hazardous substances (Swedish EPA 2018). In this sense, a producer is defined as anyone placing a product on the market, be it a manufacturer or an actor who imports the product.

The Ellen MacArthur Foundation is a non-profit charity organization launched in 2010 with the mission to accelerate the transition to a circular economy. Since its establishment it has promoted circular economy on the agendas of decision makers in businesses, government and academia. Four essential building blocks of a circular economy have been identified by the Ellen MacArthur Foundation: Circular economy design, new business models, reverse cycles, and enablers and favorable system conditions (Ellen MacArthur Foundation 2017). The first building block (circular economy design) means that companies need to cultivate core competencies in circular design, i.e. to design products to facilitate reuse and recycling. This includes taking consideration of material selection, standardized components (easy to replace), products that are designed to last, products that are easy to sort when the product has become waste, and products that are easy to separate for reuse and recycle of its substituent materials. The second essential building block also involves producers to create new business models to promote circular economy. This can for example include business models for

The Ellen MacArthur Foundation offers school and college resources to challenge students in terms of the “take-make-dispose” economy (linear economy) to build long-term sustainable systems.

The resources can be found at: <https://www.ellenmacarthurfoundation.org/resources/learn/schools-colleges-resources>

Box. 7. *School and college resources on the circular economy.*

sharing, leasing and take-back systems.

In the midst of increased environmental awareness, new actors can be found on the market dealing with secondhand products with business models in line with the circular economy. Companies such as Inrego with its base in Sweden specialize in refurbishing computers and computer equipment and selling them on the secondhand market. They collect used computers, phones and other used computer equipment mainly from companies, authorities and other larger organizations but sometimes also from individuals (Inrego 2018). Another example is Swappie, currently active in Sweden and Finland, that specializes in secondhand iPhones and the secondhand phones are purchased both from other companies and from individuals before being refurbished and sold again (Swappie 2018). One of the upsides with these types of companies and business models is that the consumer can feel safer in terms of buying a functional product with return rights and guarantees as opposed to buying the same products in secondhand stores.

Fairphone is an example of a more circular business model for phones. Starting as an awareness campaign in 2010, the Amsterdam-based company is now active in 20 countries. The company sells modular phones so that when a part of the phone is broken, it can be replaced with a new one (Fairphone 2018). This way the phones are made to last longer, for example if the display or the battery is broken a new module of that specific part can be purchased and the parts are made so that they can be changed easily by the consumer with the help of online tutorials. Another feature is that the Fairphone (Fairphone 2) comes with two SIM slots making it easier to, for example, have both work and private phone activities on the same phone (Fairphone 2018). This might prevent consumers from owning two sets of phones while being able to separate work from private life. The company also offers a discount when you send them your previous phone which is then sent to recycling. Fairphone also

works towards a transparent supply chain (which is often a very complex one when it comes to electronics!) in order to prevent the use of materials and manufacturers coupled with social and/or economic injustice and environmental problems.

Another example on circular business models is lighting-as-a-service. Companies and public institutions may purchase “light” as a function instead of the actual products necessary to attain the same function. In other words, a service company takes care of customers’ lighting needs, including installation, maintenance and operation, electricity, and monitoring for a monthly fee or on a pay-per-use basis. As mentioned, this type of business model creates incentives for the service company to create long-lasting products and systems as it will be in their economic interest. Companies that offer this type of service include Philips (the Netherlands, global), Digital Lumens (USA, global), and Ledlease (the Netherlands) (Accenture 2016).

5.3. Governmental actors

Governmental actors such as the EU, national authorities and local authorities play a significant part in directing the management of electrical and electronic products and waste to a more sustainable system through the implementation of legislation and policy instruments.

In the EU, the following significant pieces of legislation have been implemented: the WEEE Directive on waste electrical and electronic equipment (WEEE Directive), the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) and the Eco-design Directive.

A consequence of the WEEE Directive is that it created collection schemes for consumers to return their e-waste free of charge with the aim of increasing the reuse and recycling of e-waste. The RoHS Directive requires heavy metals such as lead, mercury, cadmium, hexavalent chromium and certain flame retardants to be substituted with safer alternatives (European Commission 2018). The Eco-design Directive provides rules for the EU that improves the environmental performance of products such as household appliances, information and communication technologies and engineering. It sets a minimum mandatory requirement for the energy efficiency of products; helps prevent creation of barriers to trade and improves quality and environmental protection (European Commission 2018).

The EU has also implemented the Circular Economy Package, an effort to transform Europe’s economy into a more sustainable one. It consists of an EU Action Plan for the Circular

Can you identify a product that has already been replaced by a service (i.e. product’s utility is accessible as a service)? Think about what other functions may be purchased as a service instead of physical products.

Box 8. *Product-to-Service questions.*

Economy including a concrete and ambitious action program covering the entire product life cycle, from production and consumption to waste management and the market for secondary raw materials as well as revised legislative proposals on waste (European Commission 2018). The revised legislative proposals include for example an increased recycling target: a common EU target for recycling 65 % of municipal waste by 2030 and economic incentives for producers to put greener products on the market and support recovery and recycling schemes for e-waste, among other waste. Further, proposals specifically revising the WEEE Directive have been made.

The proposed revisions within the CE package include general requirements for Extended Producer Responsibility (EPR, as described below), requiring financial contributions by producers to EPR schemes so that they can be modulated based on necessary costs to treat their products when they become waste (European Commission 2016).

5.4. Extended Producer Responsibility (EPR)

Extended Producer Responsibility means that every producer that places electrical equipment on the market is also physically and financially responsible, to a significant degree, for the environmental impacts of their product throughout the product life-cycle (OECD 2018). This includes upstream impacts such as the selection of materials in the products but also downstream impacts such as the use and disposal of the products once it becomes waste. Within the producer responsibility the producers are therefore obliged to finance and make sure their products are collected and recycled in an environmentally sustainable way when the product has become waste. Everyone placing a product on the market is defined as a producer whether they manufacture or import the products (El-Kretsen 2018).

Besides organizing and financing take-back collection schemes, the obligations of the producers include registering on a national register, declaring the material placed on the market and informing end-users (e.g. consumers) on how to best dispose of the product at the end-of-life stage



Figure 21 (above). Battery box in Sweden.



Figure 22 (right). “Samlaren”, cabinets for collection of e-waste.

(from an environmental point-of-view). The product must also be labelled with the proper icon (a crossed-out wheelie bin) to clearly show the end-user that this product should not be disposed of in a regular trash bin. The producer must also make information available for recyclers on how to dismantle the product, avoid pollution and recover the product (WEEElogic 2018).

Most producers manage the abovementioned responsibilities through EPR organizations where producers create a common take-back system that they finance together. Examples of such EPR organizations are El-Kretsen in Sweden, REPIC in Great Britain and UFH in Austria (WEEE Europe 2018). EPR organizations make it possible for the financing of the collection systems to be more economically viable and logistically easier to manage compared to separate take-back systems established by individual producers. For example, El-Kretsen has the task of providing a national take-back system and collaborates with all 290 municipalities in Sweden as well as with recyclers (El-Kretsen 2018).

5.4.1. How EPR works in Sweden

Extended producer responsibility applies in Sweden as in the rest of the EU and, as mentioned before, El-Kretsen is the EPR organization responsible for the organization and financing of the take-back system, collaborating with municipalities and recyclers. Consumer products are col-

lected through the municipal collection system, El-Kretsen’s battery boxes or via retailers (ibid.).

There are approximately 10,000 battery boxes, 600 recycling centers and 30 recycling facilities in Sweden (El-Kretsen 2018). The battery boxes can be found in connection to many pharmacies, grocery stores, shopping malls and retailers and sometimes also in connection to recycling stations where residents turn in their packaging waste, Figure 21. Batteries are also collected at recycling centers and in “Samlaren” (translated: “the collector”).

“Samlaren” is a cabinet for the collection of spray cans, light bulbs and other light sources, batteries and smaller electric and electronic devices such as mobile phones (Stockholm Vatten och Avfall 2018). The cabinets can be found in numerous places often in connection to supermarkets, Figure 22.

E-waste can of course also be turned in at one of the 600 recycling centres where most waste types are collected, Figure 23 and Figure 24.

Since 2015 retailers of electric and electronic devices are obliged to accept e-waste, meaning that consumers can also turn in their e-waste directly to the retailer (El-Kretsen 2018). Retailers include both physical and online stores where electric and electronic devices can be purchased. Larger retail-stores can accept all consumer electronics smaller than 25 cm. In other stores, a consumer can turn in an old device when pur-



Figure 23. A typical recycling centre in Sweden. (Source: Recycling, 2015)

chasing a new one. The collected devices are then turned in to a certified system for recycling (ibid.).

If businesses wish to turn in e-waste, they can find collection points in their municipalities free of charge. Some businesses are large enough to handle their own e-waste and may as a consequence qualify as a collection point on its own.

Before the products turn into waste however, the consumer has the alternative to turn in the products to various secondhand actors such as Myrorna, Stadsmissionen and the secondhand online store Blocket or refurbishment companies like the ones previously mentioned (e.g. Inrego and Swappie).

According to the aforementioned waste hierarchy, it is better for the environment to firstly use

A film (in Swedish) on how recycling of WEEE works can be found here:
<http://www.el-kretsen.se/el-kretsen-s%C3%A5-funkar-det>

Box 9. Link to a film in Swedish on how e-waste recycling works .

the product for as long as possible, secondly to reuse it and thirdly to recycle it. Considering this, the individual consumer of electronics should first consider purchasing a secondhand item instead of buying a new one, after careful consideration of whether the product is even necessary to own. It might be possible to rent, lease, borrow or share the product.



Figure 24. E-waste turned in at municipal recycling centres. (Source: Vimmerby Energi & Miljö AB, 2018)

5.4.2. Other countries

In Italy, the implementation of the WEEE Directive has established the opportunity for producers to join one of several compliance schemes (Ecodom 2012). Before the WEEE Directive came into force in Italy, household e-waste was collected along with other household waste from municipalities and transferred to treatment centers that do not always have the adequate equipment for disassembly, shredding and separation of various fractions necessary for recycling. Today, the collection scheme provides pick-up of e-waste from all collection centers connected to the scheme, both municipal and retail collection points (Ecodom 2012). The consumer is obliged to hand over e-waste to these collection points or to retailers.

In Spain, the Royal Decree (110/2015) on Electrical and Electronic Equipment incorporates European directives into national legislation regarding producer responsibility (Ecotic 2018). The Royal Decree objectives include (Ministerio para la transición ecológica 2015):

- Establishing a clearer regulation to increase the level of legal certainty and to establish a detailed description of the obligations of users, manufacturers, authorized representatives, importers, distributors and managers.
- Integrate a single control instrument on regional and national e-waste data to identify compliance with objectives in this field and to ensure traceability and appropriate management of waste.
- Promote reuse and preparation for reuse, encourage creation of reuse centers and job creation.

- Provide reliability and systematize reporting obligations of electric and electronic producers and e-waste managers on the collection and recovery of e-waste, ensuring uniformity of e-waste management.

- Economically optimize and efficiently manage e-waste under the extended producer responsibility.

Ecotic is the organization in Spain responsible for the financing and management of e-waste (Ecotic 2018). The three main collection points in Spain are (Ecotic 2018):

- Recycling points and other municipal points.
- Distribution company warehouses where waste is stored.
- Load Grouping Centers fitted out by Ecotic that accept e-waste from recycling points and distributors before it is transported to recycling companies.

E-waste may also be turned in at retailers when purchasing a new product and they also have to accept devices smaller than 20 cm regardless if the consumer purchases a new product or not (ibid).

In Ireland, WEEE Ireland is the main EPR organization responsible for the collection and treatment of e-waste on behalf of the producers (WEEE Ireland 2018). They have been operational since 2005 and it is now possible to turn in consumer e-waste at local recycling centers, public collection days, retailers and bulb exchange stores. Batteries can also be recycled at local newsagents and grocery retailers (ibid.). Retailers, wholesalers, health facilities, public and private businesses and schools can request battery boxes, trolleys and other collection boxes to place in the facility free of charge for the collection of e-waste.

6. COMMUNICATION STRATEGIES FOR INCREASED CIRCULAR MANAGEMENT

In order to increase awareness and as a consequence the collection, reuse, and recycling of e-waste, various communication strategies have been conducted. Here, some examples of successful communication strategies are presented.

“Batteriåtervinningen” (translated: “the battery recycling”), is an initiative by Swedish battery producers started by Blybatteriretur (an EPR organisation for lead batteries in Sweden), El-Kretsen and Recipo (an EPR organisation for e-waste and batteries active in all Nordic Counties since 2007) (Blybatteriretur 2018, Recipo 2018). Since 2012, Batteriåtervinningen has been responsible for informing the Swedish people on why it is important to recycle batteries (Batteriåtervinningen 2018). On the home page of Batteriåtervinningen the consumers are informed about where the closest collection point for batteries are, why it is important to turn in used electric and electronic products, present recycling statistics, inform about the negative environmental effects of batteries when not discarded properly and more. Batteriåtervinningen are also active on social media such as Facebook, Twitter and Instagram to reach as many consumers as possible with updated information. They also created popular events on Facebook in different Swedish cities, inviting the public to “Electric flea markets” where consumers could reuse and share electric and electronic equipment.

Batteriåtervinningen have also produced material for schools to use. “Sopskolan.se” (translated: trash school) for example provides interactive educational material about hazardous waste targeting students aged 14 to 16. The material is produced by the Swedish Waste Management Association, El-Kretsen, and school informers.

“Batteriskolan” (translated: the battery school), is an online school with material for younger students informing them about batteries, recycling, and other environmental issues (Batteriåtervinningen 2018). The schools are developed by Keep Sweden Tidy, a non-profit organization promoting recycling and working for the mitigation of litter (HSR 2018).

A project called ELAN (ELektronik ska återANvändas, translated: “Electronics should be reused”), conducted within the strategic research program RE:Source and financed by the Swedish Energy Agency and partners within the project, studied and tested methods to increase the reuse of electric and electronic equipment (Torres, Björnsson et al. 2018). The methods tested include returning shipment notes to return used electronics when purchasing new products online, customizing collection boxes/cargo carriers for electronics at recycling centers, collecting and testing used electronics in-store, collecting and testing the functionality of appliances, and other information measures. The information measures included opinion pieces, press releases, radio clips, conference presentations and a Facebook campaign.

The information campaigns within the project were estimated to have a relatively good potential to change people’s behavior (ibid.). Information about the problem with electronic waste and the benefits of reuse and recycling was communicated in various channels and to a broad and varied target audience. Although it is difficult to measure the communication’s effects, it is important to raise awareness by lifting the issue in the public sphere to inspire a more sustainable consumption and lifestyle. The partners of the ELAN-project chose two measures to continue with after the completion of the project: the Facebook Campaign Circular Electronics Day and the return shipment note approach. The goal of the Facebook campaign was to establish a national day for the reuse of electronics on the 24th of January, a day when many have empty wallets after the holidays. A Facebook page was created with many posts on environmental benefits and practical tips on reuse. A special logo was also created for the page (Ibid.).

7. COMMUNICATION CAMPAIGNS BY STUDENTS

This chapter presents some ideas for communication campaigns that can be conducted by students in schools with the aim to increase awareness on preventative actions and e-waste management.

Based on the knowledge and information on e-waste, environmental impact, collection, reuse and recycling and circular business models given in other chapters in this book, various communication campaigns may be conducted. Digital communication channels are superior tools in spreading the message to many consumers at the same time. A few suggestions are:

- Making information films on YouTube.
- Creating an Instagram-blog discussing and bringing up issues regarding e-waste.
- Challenging companies to improve their sorting and product management methods at the end-of-life phases of their products, through LinkedIn.

Make sure the students are aware of the purpose of the communication campaigns and who their target group is so that the campaign is adjusted for the target group. What are the obstacles in e-waste management that they want to address and how can they be addressed? By who?

The communication campaign can also be combined with the competitions, for example, arranging a communication campaign competition and a film gala to present the final film products. If resources are available, a competition between different schools is also an option for a larger and more ambitious event. Here, professional film directors and/or campaign managers and consumption experts can also be invited to join a jury.

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