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Towards a Circular Economy for the Electronics Sector in Africa:

Overview, Actions and Recommendations

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ABBREVIATIONS

9Rs	Reduce by design, Refuse, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle
ASM	Artisanal and small-scale mining
CE	Circular economy
CFC	Chlorofluorocarbon
CoC	Chemicals of concern
CO2	Carbon dioxide
EDC	Endocrine disruptive chemical
EEE	Electrical and electronic equipment
EoL	End-of-life
EoU	End-of-use
EPR	Extended producer responsibility
EPRON	E-waste Producer Responsibility Organisation Nigeria
EU	European Union
FRs	Flame retardants
GDP	Gross domestic product
GHG	Greenhouse gas
HCFC	Hydrochlorofluorocarbon
MSMEs	Micro-, small and medium-sized enterprises
NGO	Non-governmental organization
PCBs	Polychlorinated biphenyls
PGM	Platinum Group Metals
PPP	Public-private partnership
PRO	Producer responsibility organization
PVC	Polyvinyl chloride
UEEE	Used electrical and electronic equipment
UNEP	United Nations Environment Programme
UNU	United Nations University
WEEE	Waste electrical and electronic equipment

GLOSSARY

Chemicals of concern (CoC). Chemical compounds or substances that have hazardous properties and can have adverse impacts on human health or the environment.

Consumer. A person or an organization (public or private) that purchases a product or service for use.

Electronics. Electronic products, equipment or simply electronics refers to common electrical and electronic equipment that requires electric current or electromagnetic fields in order to operate, as well as batteries powering such equipment. See Table A.1 in Annex A for an indicative list of electronic devices considered in this report.

End-of-life. Refers to the point in a product or object's service life at which it no longer functions or performs as required, and the only option is to recycle or dispose of it.

End-of-use. Refers to the end of a product's service life from the perspective of its current owner or user, but for which other options are available to keep the product and/or its components within the market.

Hotspot. Refers to a component of the system that directly or indirectly contributes to natural resource use and its associated impacts either as a driver of unsustainable practices or a barrier to sustainable practices, and that can be acted upon to mitigate it.

Informal sector. Unincorporated enterprises or self-employed individuals that are not registered, regulated or protected by existing legal or regulatory frameworks. Typically, informal workers do not have secure employment contracts, workers' benefits, social protection or workers' representation.

Life cycle thinking. Refers to the consideration of the environmental, social and economic impacts of a product over its entire life cycle, rather than focusing solely on the production site and manufacturing processes.

Producer. Product makers and manufacturers. This includes manufacturers of electronic product components and sub-assemblies. In the context of EPR, importers and distributors are included as well.

Recycling. Any recovery operation by which waste electronic products are processed into new products, materials, or substances. A distinction is made in the report between formal and informal recycling and energy recovery is excluded.

Refurbish. Modification of an electronic product or waste object to increase or restore performance and/or functionality or to meet applicable technical standards or regulatory requirements. Refurbishment usually results in a fully functional product, satisfying at least the original intended purpose.

Refuse. Indicates a user's choice to buy or use fewer products and services. This involves shifting to a more sustainable lifestyle, for example by rejecting packaging, shopping bags or other products and services that are deemed unnecessary.

Remanufacture. Implies a product improvement, whereby the entire structure of a multi-component product is disassembled, checked, cleaned and, where necessary, replaced or repaired in an industrial process. The remanufacturing process meets specific technical specifications regarding engineering, quality, and testing standards, and typically yields 'as-new' or better, fully warranted products.

Repair. Fixing a specific fault in a defective electronic product or electronic waste (e-waste) object to restore partial or full functionality so that it serves its original intended purpose.

Repurpose. Implies the creation of a distinct new life cycle for a material, by reusing discarded goods or components that are adapted to serve a function other than that originally intended for the product.

Reuse. Using an electronic product again for the same purpose for which it was designed, without the needing to repair or refurbish it. Reuse often involves a change of ownership for a product, either through a direct handover, or through second-hand markets.

Second-hand. Refers to used and functioning electronics available for purchase. Electronics may have multiple owners throughout their lifetime.

Stakeholder. Any actor that has an impact on and/or that is impacted by the electronics value chain.

Value chain. All the activities that provide or receive value from designing, making, distributing, retailing and consuming a product, as well as activities after product end-of-use and end-of-life. The value chain covers all the stages in a product's life, from the supply of raw materials through to the product's disposal after use, and encompasses the activities linked to value creation, such as business models, investments and regulation.

SUMMARY

The consumption of electronics has been on the rise, accelerated by digitalization, global population growth, shortened product lifetime and affordable products in the market. The electronics industry relies on a global value chain, benefiting billions of people with its products and employing millions. However, **linear, rather than circular, approaches are still dominant in today's economy in the electronics sector and there is also a variety of environmental, social and economic hotspots along the value chain.**

The African region is of particular interest, being a source of many of the raw materials used in electronics, while it imports most of the electronics it uses (a large part of which are second hand), has limited infrastructure to deal with the resulting electronic waste (e-waste) and underdeveloped domestic markets to absorb the recycled materials it generates.

Africa's rapidly growing population and economic development have resulted in an increase in the consumption of electronics, at one of the fastest rates in the world, second only to Asia. Nonetheless, as Africa's domestic production of electronics is still at a relatively low level, it relies heavily on imported products, primarily from Asia. In addition to new products, used electronics and e-waste are commonly imported: this generates rapidly growing amounts of e-waste and poses a major challenge for the continent. The amount of e-waste generation varies significantly among African countries. **Less than 1% of Africa's e-waste is collected through official schemes, and the majority of waste electronic products are collected and treated informally in suboptimal conditions**, resulting in pollution and endangering the health of informal workers and persons living nearby. In 2019, 4.4 megatons (MT) of electronics were put on the African market, China and the EU being the major exporters of electronic products to Africa. In the same year, 2.9 Mt of e-waste was generated, of which only 0.03 Mt were documented for collection and recycling. While policy approaches, such as extended producer responsibility (EPR), could improve e-waste collection and treatment, functioning EPR schemes in most African countries are still scarce, despite efforts to create such systems are currently under way in several countries, including Nigeria, Ghana, South Africa, Senegal, Côte d'Ivoire and Kenya.

On the other side, opportunities for a more circular electronics economy are also emerging on this continent. The appropriate and responsible design of products and business models is key to moving towards circularity in the electronic value chain. Africa is a major mining source of aluminium, gold, cobalt, copper, iron, mercury, lithium and platinum which are major elements used in electronics production. Since Africa's production of electronics is limited, the design stage usually takes place elsewhere. Raw materials for electronics production are exported from Africa, converted into products elsewhere in the world and then some are imported into Africa. However, this may change in the future, as several countries are now attempting to establish electronics production and relevant centres of competence in the region. Furthermore, many African countries' economies are expected to grow significantly, and such expansion should be counterbalanced by appropriate measures to decouple economic development and the consumption of electronics. While the lifespan of products should be extended as much as possible through a combination of design, policy, finance and information, the matching capacity to collect, process and recycle the resulting e-waste should also be developed. The informal structures that are currently operating most of the electronics repair and end-of-life (EoL) processes should be considered and integrated into newly established formal capacities. Finally, an array of enabling conditions, including on policy, education, innovation and financing is required to move towards a more circular and sustainable electronics value chain in Africa.

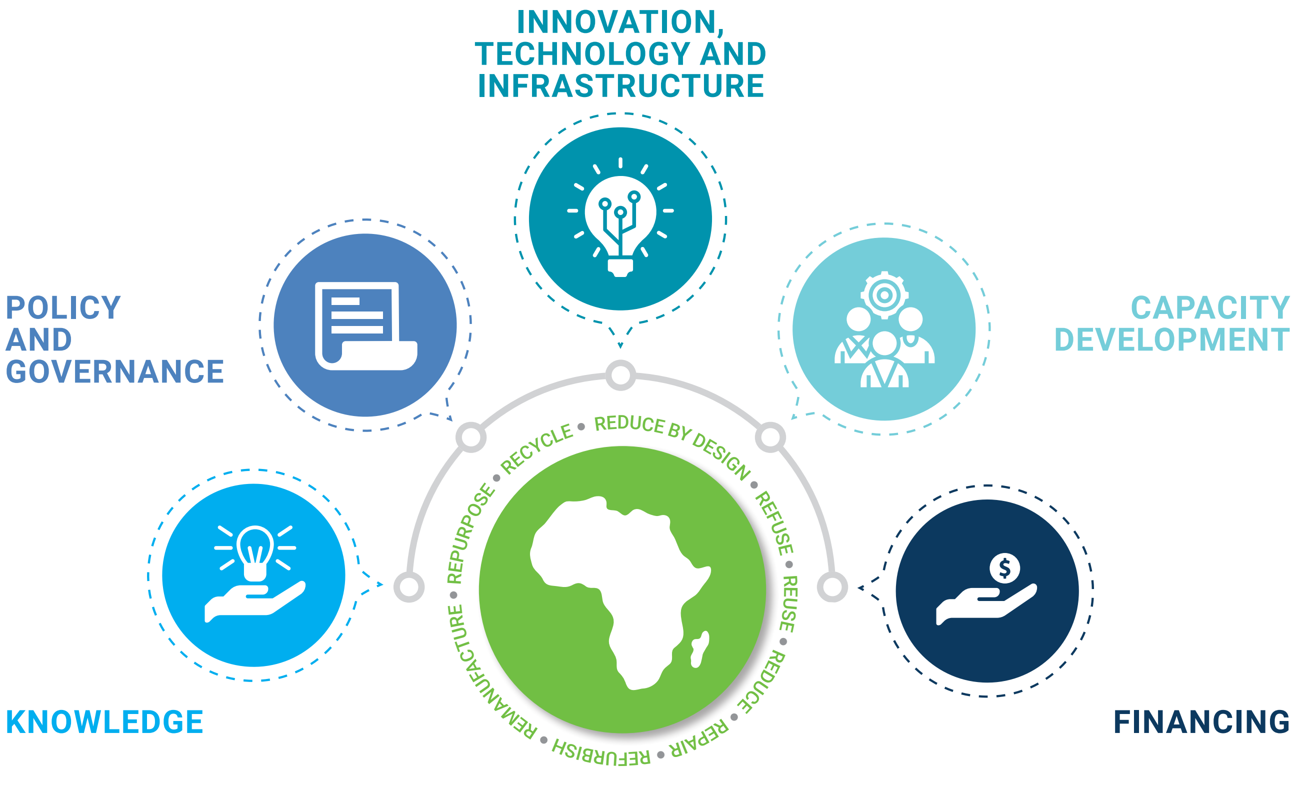
This report provides an overview of the current state of circularity in the electronics value chain in Africa, identifies key areas of concern, provides appropriate recommendations, and proposes priority actions to improve circularity of the sector. The recommendations focus on the individual life cycle stages of the electronics value chain, as well as on aspects that cut across the value chain. The transition towards a more circular electronics sector in Africa would require a holistic, coordinated approach bridging five key areas covering knowledge, policy and governance, innovation, technology and infrastructure, capacity development and financing, as illustrated in Figure S.1 below. The report also proposes a list of priority actions to be taken by a variety of key stakeholders, including policymakers, businesses, civil society groups, researchers, etc. While an attempt has been made to identify the most relevant actions and tailor them to the African region, the list is not exhaustive and proposed actions may also be applicable elsewhere.

Overall, the key recommendations for action can be summarized as follows:

- Set minimum design and product requirements for electronics put on the market in Africa
- Integrate informal collectors and create new channels for formal electronic waste collection
- Significantly expand formal infrastructure for recycling waste electronics
- Treat non-recycled fractions (e.g., containing hazardous chemicals) in environmentally sound processes
- Provide policy instruments facilitating transitions to a more circular value chain (policies such as EPR schemes, regulations and standards, etc.)
- Facilitate access to circularity-focused financing for all stakeholders across the value chain, with particular attention to micro-, small and medium-sized enterprises (MSMEs)
- Create and share knowledge, to foster innovation and capacity development

This report can be used as a reference by governments, businesses and other relevant stakeholders to define, facilitate and scale up their actions to promote circular economy for electronics, in particular in the context of Africa. UNEP will continue supporting governments to develop integrated policies to increase the circularity along the electronics value chain, collaborating with the industry on innovative solutions, and developing knowledge and capacity to increase uptake of best practices. UNEP also encourages all stakeholders to take the systemic approach, for an effective transition towards a toxic-free and more circular electronics value chain at local, regional and global level.

Figure S.1. Schematic representation of the main building blocks for the recommendations towards circular economy for electronics in Africa.



1. THE CIRCULAR ECONOMY AND ELECTRONICS

The essential requirement for sustainable development is to achieve sustainable consumption and production, which can be advanced through the circular economy and other sustainable economic models (UNEP, 2019a). To support the transition from circular economy principles to actions, UNEP has published its vision of and approach towards circularity on the UNEP circularity platform (https://www.unep.org/circularity). It has also identified key interventions to improve the circularity of various sectors and value chains, by providing support to governments in emerging economies, engaging with global and local producers, organizing communication campaigns and facilitating dialogue with leaders on national, regional and international scales.

1.1 A circular economy for electronics at global level

A circular economy is a regenerative system, inspired by nature-based solutions, in which all materials and components are kept at their highest value at all times, with hazardous materials and waste designed out of the system (WEF, 2019). It represents a sharp contrast to the prevalent linear value systems, commonly referred to as "take-make-consume-dispose". Making use of life cycle thinking, the circular economy aims at disconnecting natural resource use and environmental impacts from economic activity and human well-being. This is achieved by keeping products and materials in use as long as possible, avoiding environmental impacts and regenerating natural systems. Vital components of the circular economy are its various business models, including product-as-a-service, sharing of assets, life extension (through improved design, repair and reuse, etc.) and finally, effective material recycling. Shifting from a linear to a circular economy requires engagement with all stakeholders across the entire value chain.

In 2019, the Platform for Accelerating the Circular Economy (PACE) and the United Nations E-waste Coalition made the case for a new circular vision for electronics explicitly focusing on key aspects of the value chain in design, production, use, EoL product collection and recycling of electronics (WEF, 2019). Drawing inspiration from the report, the ideal outcomes of implementing a circular economy in the electronics sector include:

Electronics are a key enabler of sustainable development for all. Electronics are reusable, easy to repair, made of recycled, non-toxic materials and have long lifetimes, minimizing adverse sustainability impacts across the value chain and creating decent jobs. After a product's end of life, most materials re-enter production at their highest level of quality and value for the industry, while non-reusable materials are disposed of in a safe and environmentally sound manner.

There is a need for a fundamental shift from the linear electronics value chain towards a circular value chain, whereby products are designed in such a way as to extend their life cycle, chemicals of concern (CoC) are eliminated from use and resources are maintained in the material loop for as long as possible. Further details on how to operationalize the circular economy for electronics are provided in the next section.

1.2 Applying the UNEP circularity approach to achieve the circular economy in the electronics sector

Figure 1.1 is a schematic representation of the above circularity processes. Since additional processes used in many countries to recover value from waste, such as energy recovery, do not maintain the value of the material in the material loop, they are not deemed part of the circularity approach.

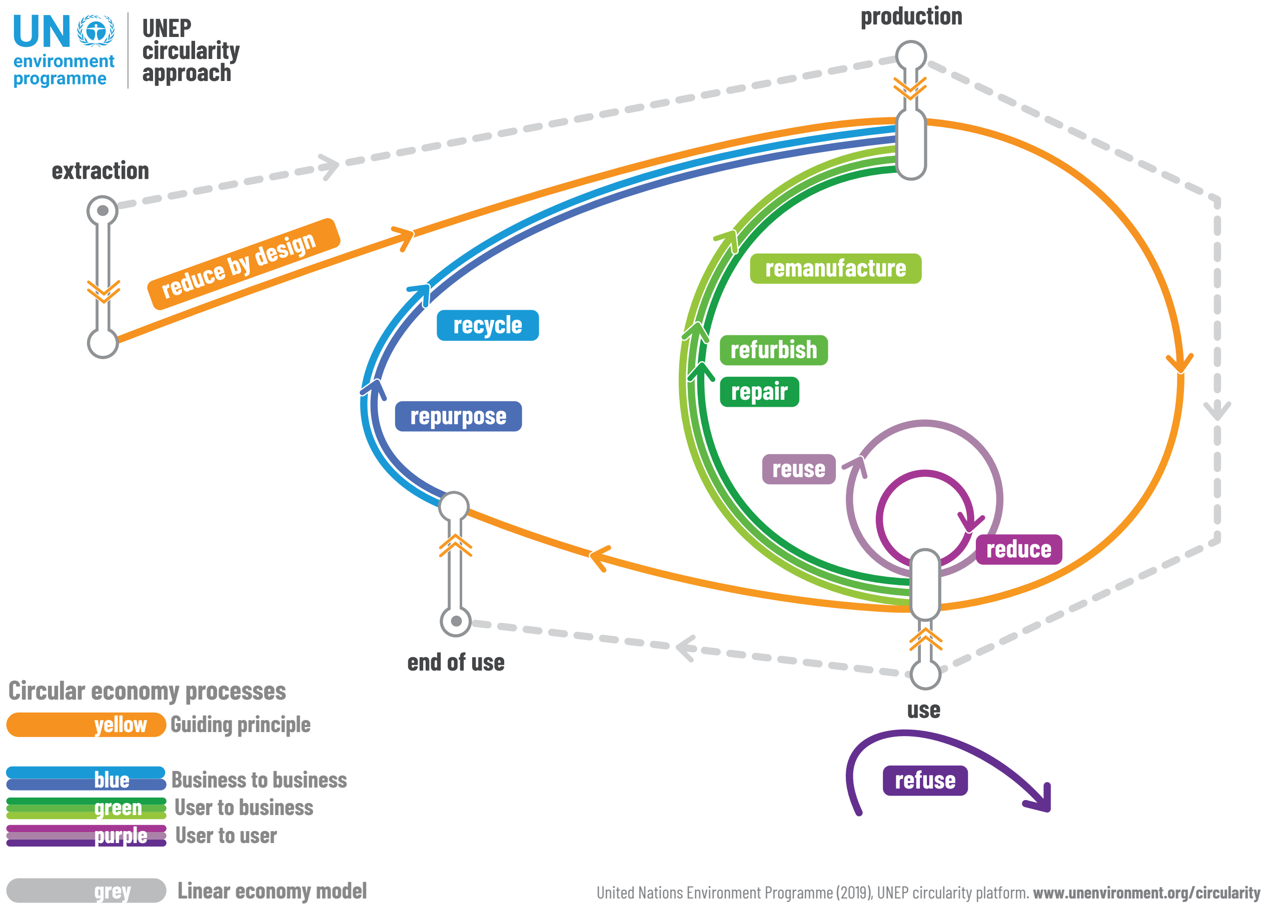


Figure 1.1. UNEP circularity approach (https://www.unep.org/circularity).

For the electronics sector, the circular economy is realized through actions upstream, mid-stream and downstream of the value chain, including at the design stage to extend product lifetime, through promoting repair and refurbishment and improving recycling. Processes contributing to the circularity of electronics can be grouped into four categories and inspired by the European Union (EU) waste hierarchy, can be ranked from the most impactful to the least, incorporating the respective 9Rs (https://www.unep.org/circularity):

1. **Reduce by design**: Reducing the amount of material used, particularly raw material, should be applied as an overall guiding principle from the earliest stages of the product and services design process. Products and services are thus designed to use fewer materials per production unit, and/or during their use and are easier to reprocess and recycle. The use of CoC should be eliminated or reduced as much as possible. The processes in this group influence all stages of a product's life cycle.
2. **Refuse**, **Reduce** and **Reuse**: The processes in this group are driven by product users, who can either refuse to buy or consume a specific product and hence send a strong signal to the market, reduce their use of products, choosing a more sustainable way to better meet their consumer needs, or reuse the product for the same purpose for which it was designed and thereby retain its value for longer.
3. **Repair**, **Refurbish** and **Remanufacture**: The lifetime of used, damaged or outdated products is extended by replacing defective components (i.e., repair), restoring a product's performance and/or functionality through maintenance operations (i.e., refurbish) or restoring the product's original as-new condition and performance, or improving it, through a standardized industrial process (i.e., remanufacture).
4. **Repurpose** and **Recycle**: Through collaboration between businesses, discarded goods or components can

be reused and adapted for another function, giving the material a distinct new life cycle. Should it not be possible to reuse goods or components directly, the waste materials are reprocessed into products, materials or substances, though not necessarily for the original purpose. CoC already present in end-of-use (EoU) and EoL electronics should be eliminated.

1.3 The need for a circular economy and report objectives

As the pace of digitalization quickens, the electronics sector is growing and is now facing a variety of challenges, from high resource use and the impact of raw material extraction and processing to the low circularity of materials and rapid generation of e-waste. Transitioning towards a circular economy can improve resource efficiency and productivity, reduce environmental impacts, promote a healthy environment for workers and local communities and limit e-waste generation. While the impacts of adopting a circular economy in the electronics sector are global, developing and transitioning economies are expected to benefit most, given their anticipated economic and population growth and resulting need for materials which, to a large degree, can be addressed by circular economy activities (UNIDO, 2019), providing appropriate attention is given to gaps and opportunities in such countries. The anticipated growth in both population and standards of living will require materials, water and energy for infrastructure development and industrial growth and will result in increased consumption. A circular economy could help to meet much of the increasing demand, slow down growing resource use and improve well-being indicators, while decreasing pressure on the environment.

This report provides a baseline analysis of the current state of the electronics sector in Africa, identifies development gaps and needs and provides timely recommendations targeting the main stakeholders in the electronics value chain in the region. While African countries are already implementing elements of a circular economy in their national legislations (AMCEN, 2019), this report provides concrete priority actions specifically focused on a circular economy for electronics in Africa. In order to provide tailored recommendations on the transition to a circular economy in the electronics sector in Africa, the region's role in the global electronics value chain and the sector's current state of affairs in the region need to be better understood. Section 2 thus provides a brief overview of the global electronics value chain, and the current situation in Africa, identifying gaps and opportunities and providing recommendations in Sections 3 and 4 where the detailed, stakeholder-specific priority actions are presented. Some of the recommended actions are already being implemented in Africa and there are a number of circularity-focused projects with various scopes, goals and ambitions at different implementation stages. Learning from the successes and failures of these projects is a key catalyst for knowledge creation, capacity-building and innovation in the sector. This report contains three selected African case studies, presented in Boxes 1-3, the core concept of which is to improve electronics circularity and that have the potential to be scaled up and replicated across the continent. The report was developed by the United Nations Environment Program (UNEP) under Global Environment Facility (GEF) funded project: Circular Economy approaches for the electronics sector in Nigeria.

2.
THE GLOBAL ELECTRONICS VALUE CHAIN

Nowadays, technology and innovation play a crucial role in economic development and the transformation of societies globally, thus improving billions of lives. The rapid digitalization of technology also means that electronics play an increasingly important role in this process. In only a few decades, electronics have become an essential part of our daily lives, changing the way we work, spend our free time and socialize. The COVID-19 pandemic has catalysed the further digitalization of many of our activities, increasing our reliance on electronics in our daily lives and work. It is expected that after the pandemic, people will be more likely to participate in virtual events and will look for more virtual experiences, which would result in a need for more devices to connect with one other and to support the growth of digital infrastructure (Coughlin, 2021).

Electronic products consist of a series of interconnected features or functionalities, creating a value chain that aligns with the main stages of the product life cycle: material extraction, processing and manufacturing, product use and EoL management. Figure 2.1 shows how all the life cycle stages of an electronic product are connected in a linear chain. While some material loops do exist within the current electronics value chain, such as a limited amount of waste reduction through design, product reuse and some material recycling, the linear “take-make-dispose” approach still dominates the sector (Baldé *et al*., 2017).

The electronic product supply chain starts with raw material extraction, refining and conversion. Important materials in the electronics industry are base metals and their alloys (steel, copper and aluminium, etc.), precious metals (gold, silver and platinum, etc.), rare earth elements (neodymium, yttrium, cerium, etc.), plastics (polypropylene, polystyrene, polycarbonate, polyvinyl chloride (PVC), epoxy and silicon plastics, etc.), glass, synthetic chemicals and their formulations. Hundreds of different chemicals, elements and formulations are used in electronics production (OECD, 2010).

An electronic product is designed and produced in four basic steps: (1) product development, where an idea and business case for an electronic product become a design and a prototype is validated; (2) manufacture of components (e.g., transistors, capacitors, connectors and wires); (3) sub-assembly (e.g., printed circuit boards, displays, control panels), and; (4) final product assembly, where subassembled parts are usually connected together in a casing. Design is a key stage of the product life cycle, where functionalities, appearance, use of components, raw materials, engineered materials and chemical substances are determined. In addition to the physical design, electronics commonly includes the software used to operate the product. A combination of the physical product (i.e., hardware) and its operating system (i.e., software) results in the final electronic product made available to the consumer.

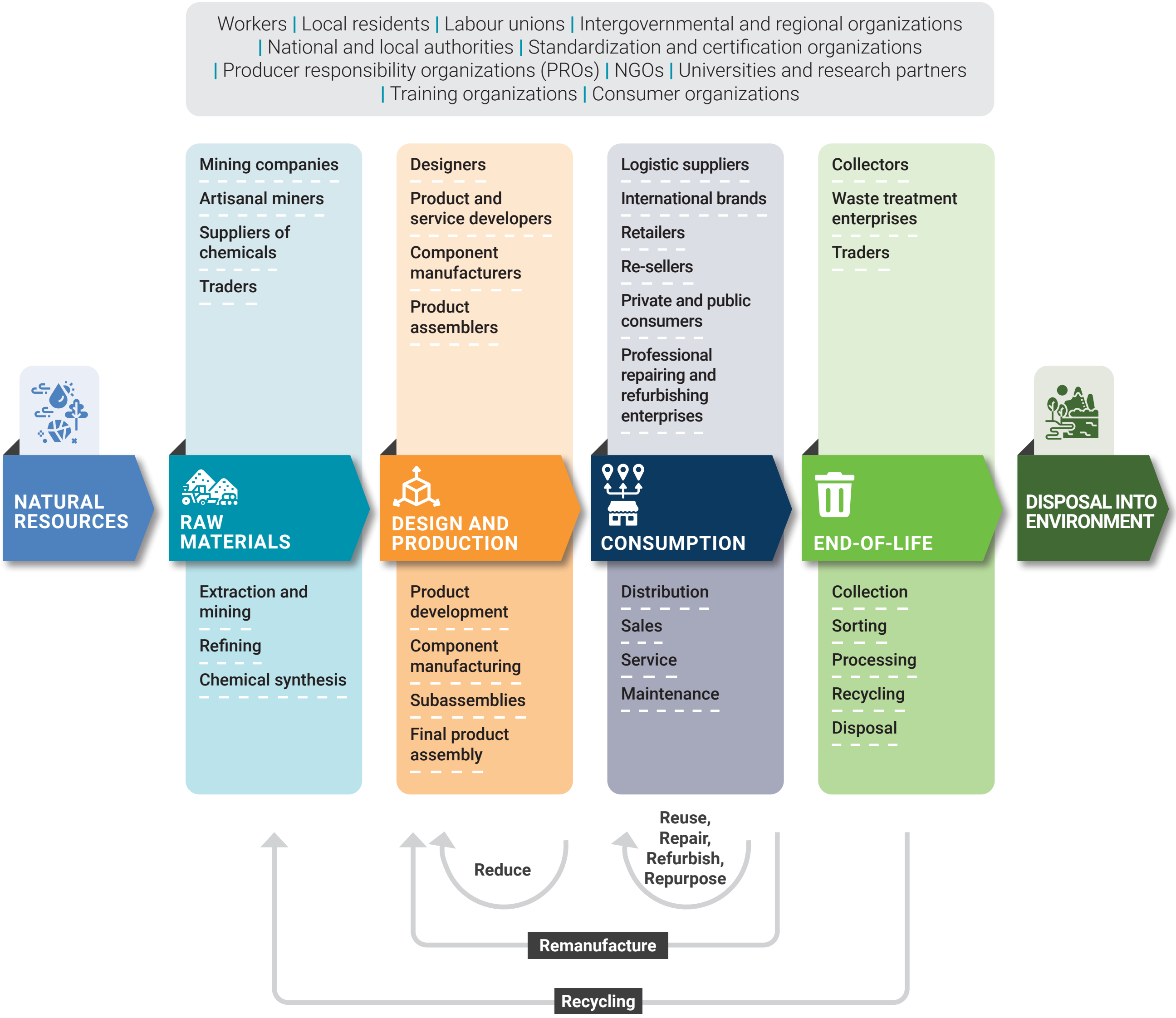
Final products can be divided into different categories, such as product application or product size. The EU classifies electrical and electronic equipment (EEE) into six categories (see Appendix A), focusing primarily on the classification of e-waste (Directive 2012/19/EU). The United Nations International Trade Statistics Database (UN Comtrade) classifies products into 5,300 six-digit Harmonized System (HS) codes, of which 270 HS codes can be regarded as relevant to EEE (Baldé *et al*., 2015). The United Nations University (UNU) developed a further the classification, comprising 900 EEE products, clustered into 660 main product types. This classification is referred to as UNU-KEYS (Baldé *et al*., 2017).

Final electronic products are made available through distribution channels tailored towards private consumers, firms or public institutions. Consumption includes a variety of sub-steps, including equipment installation, training, servicing, maintenance and repair. Products considered obsolete by their current owners and/or users, due to a malfunction or lack of need, for example, reach the EoU stage, after which the electronic products or their components can still be reused, repaired, refurbished, or repurposed. The electronics sector is characterized by a relatively high degree of reuse, as many used products are re-sold on second-hand markets. Lower-income countries are expected to have larger second-hand markets and be net importers of used electrical and electronic equipment (UEEE), compared to higher-income countries, which are usually net exporters.

Ideally, once the value of an EoU product or its components cannot be retained in the system, it enters the EoL stage. Due to its composition, waste electrical and electronic equipment (WEEE) or e-waste is considered special or hazardous waste and should be collected and managed separately from other types of waste. Collected e-waste is then usually sorted by product type, disassembled, shredded, sorted by material type (glass, plastic, metal, etc.) and valuable materials are recovered. Materials recovered from e-waste are sold on the market, making their way into new products either in electronic or other industries. Material with no economically feasible recovery route or contaminated materials, such as flame-retarded plastics, are disposed of through incineration (with or without energy recovery) or landfilled.

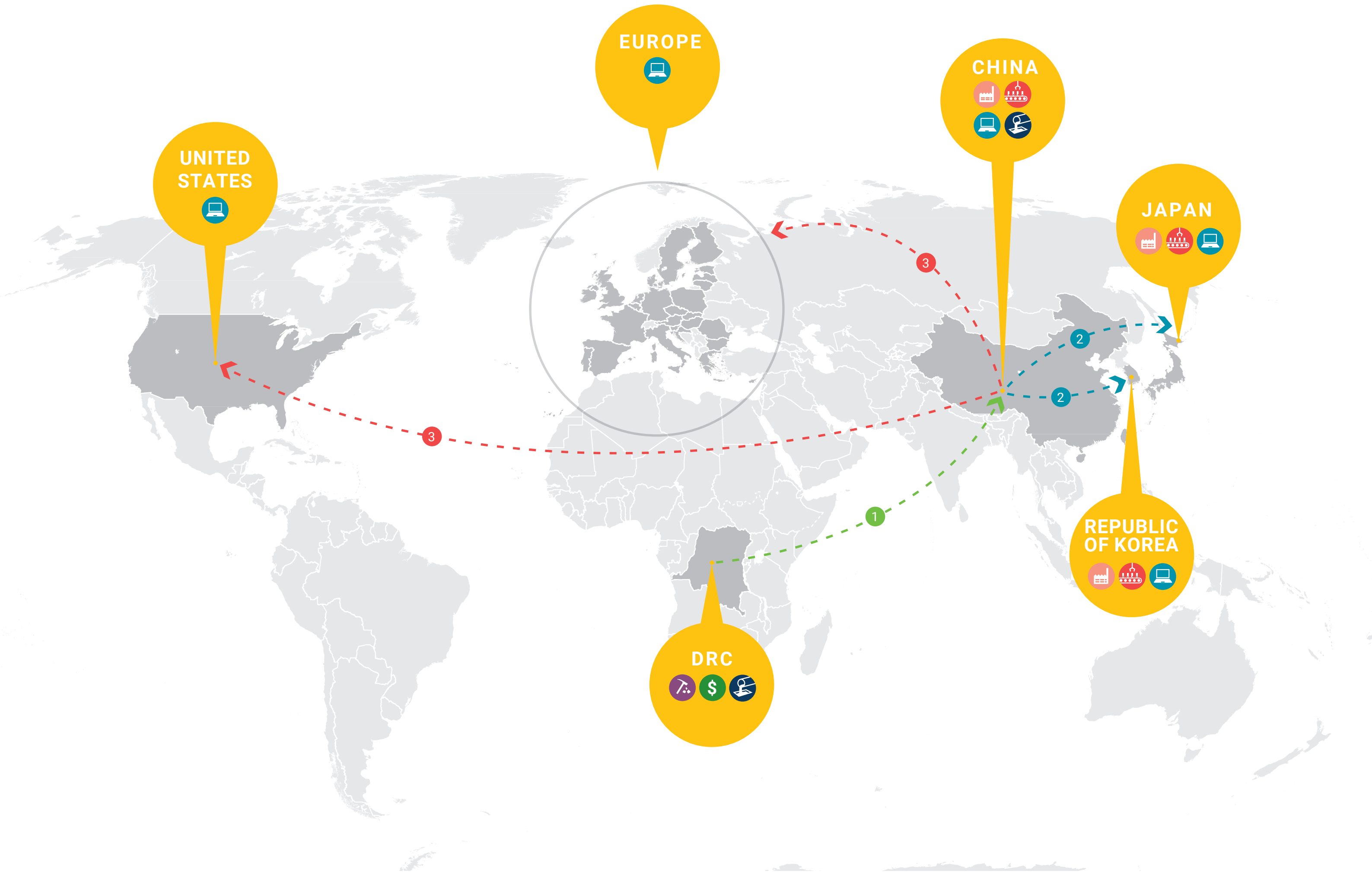
Electronic products are part of the global value chain involving many countries around the world. Raw materials, semi-finished sub-assemblies and finished products, as well as waste[1] and recycled materials recovered from waste are transported between industries, countries and continents. Many of the raw materials used in electronics come from Africa, South America and Asia, while electronic consumption, and the production and assembly of electronic components occur primarily in Asia (see Chapter 2.1 for more details about global consumption and production of electronics). To illustrate the global nature of the electronics value chain, Figure 2.2 provides the example of cobalt, a key component of lithium-ion rechargeable batteries, commonly used in portable electronics. Over half of the world's cobalt originates from the Democratic Republic of the Congo, and is usually exported to countries in Asia. Imported cobalt is used in electronic components, including batteries, and products, which are then supplied to the global market for consumption predominantly in Asia, Europe and the United States of America.

Figure 2.1. Schematic representation of the electronics global value chain and the associated key stakeholders.



1 E-waste is categorized as hazardous waste and its transboundary movement is controlled according to international and regional conventions (see Chapter 3.2).

Figure 2.2. Supply chain of cobalt from the Democratic Republic of the Congo (DRC) for the electronics industry (African Resources Watch and Amnesty International, 2016).



Artisanal mine | Trading centre | Smelting / refining centre | Component producer | Battery manufacturer | Consumer brand

1 Export of cobalt from DRC artisanal mines to China for processing. Over half the world's cobalt comes from the DRC, 20% of which is from artisanal mines.

2 Supply of processed cobalt to factories in Asia to make rechargeable batteries.

3 Supply of batteries to global technology and car companies.

2.1 Global electronics consumption and production

Fuelled by the increase in global connectivity and rapid economic development of a number of economies, consumption of EEE is on the rise. As more people become connected to the internet, the consumption of smartphones, tablets and laptops increases, while income growth in countries with low and mid purchasing power parity also results in more fridges, washing machines, heating units and flat panel televisions being produced and bought (Baldé *et al.*, 2017). Future developments in connectivity suggest an increase in workloads outside enterprises using, for example, centralized cloud data centres, which will reduce the need for local data centres and IT equipment used by companies. At the same time, the consumer segment of interconnected devices is expected to grow, with the number of connected devices expected to be more than three times the global population by 2023 (Cisco, 2020).

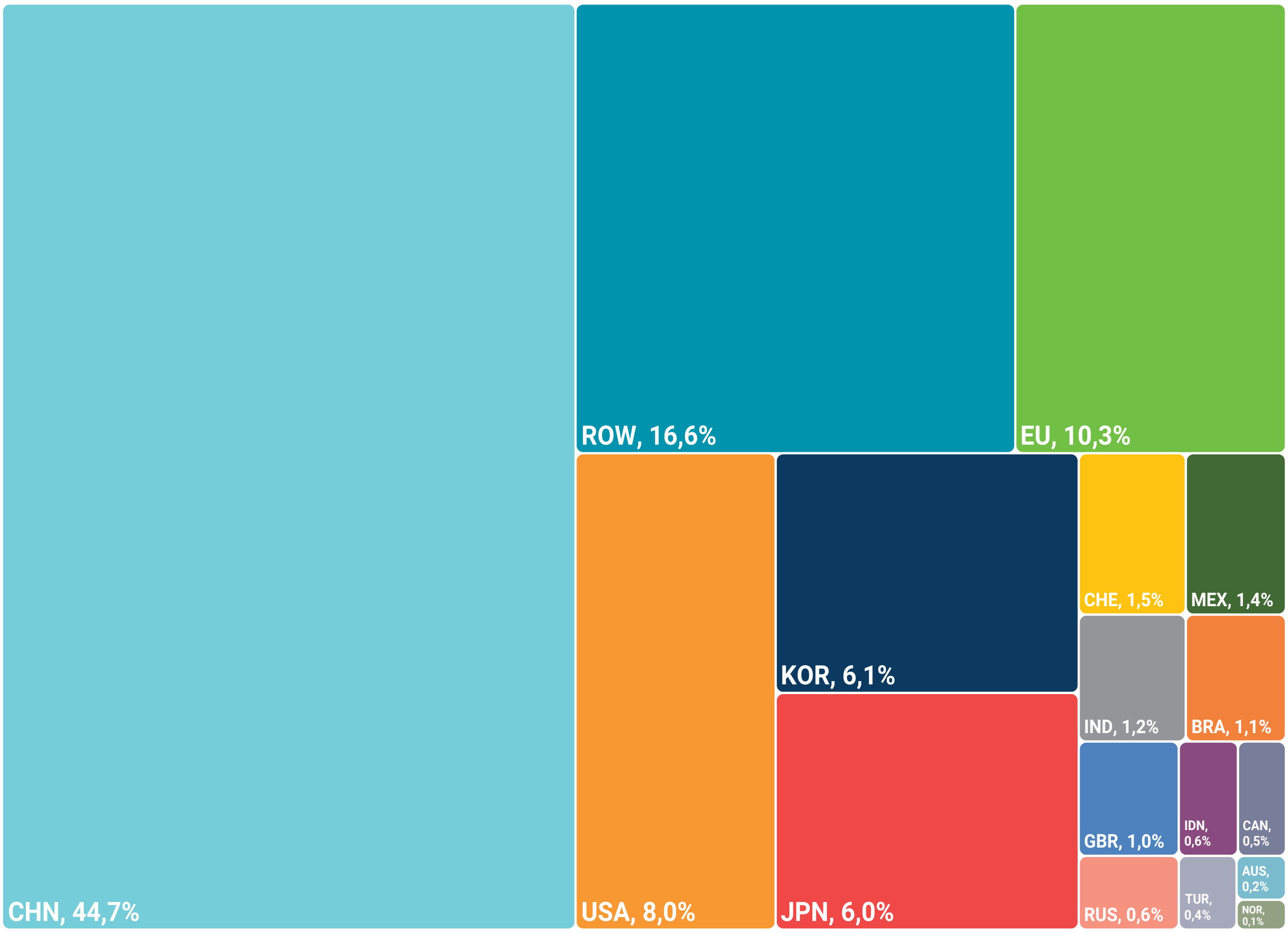
It has been estimated that more than 77 million tonnes of electronics were put on the global market in 2019 (Forti *et al.*, 2020). Most electronics (more than 50%) were consumed in Asia, followed by Americas (more than 20%) and Europe (18%). The regions with the lowest electronics consumption were Africa and Oceania, with less than 6% and approximately 1%

of global consumption, respectively. Taking regional population into consideration, per capita consumption in 2019 ranged from 19.7 kg for Oceania to 3.8 kg for Africa.

While electronics are part of a global value chain, due to globalization trends over recent decades and the increasing complexity of the value chain, most production is concentrated in a single country: China. Expressing the production data in monetary equivalents, Figure 2.3 illustrates that in 2014, the Chinese manufacturing industry accounted for approximately 45% of global electronics production. It was followed by the EU (10%), the United States (8%), the Republic of Korea (6%) and Japan (6%) as major producers. Together, the five major producers account for 75% of global electronics production.

China is also the largest exporter of EEE and EEE components, with a share of the exports destined for consumption in Africa. While this offers affordable electronics and satisfies growing demand, resulting from the region's economic development, many importing countries may lack product-specific regulations and standards on quality and use of chemicals, testing capacity for new products, as well as appropriate e-waste collection and treatment systems, or material recycling capacity.

Figure 2.3. Share of global EEE production in 2014 (World Input-Output Database, 2016 (http://www.wiod.org/)). Rest of the World (RoW) represents 140 countries, for which individual data has not been reported due to relatively small volumes.



2.2 E-waste generation, management and transboundary movement

After use, broken or obsolete electronic devices become e-waste, thereby contributing to the rapidly increasing amounts of such waste globally. Approximately 54 million tonnes of e-waste were generated in 2019 (Forti *et al.*, 2020). E-waste is considered one of the fastest growing waste streams and, if the trend continues, the amount of e-waste generated is expected to grow to 120 million tonnes by 2050 (Kuehr, 2019). This is a cause for concern, as currently, less than 20% of e-waste is documented as being collected and properly recycled and most global e-waste flows (i.e., 80%) are not documented. The majority of non-documented e-waste is likely to be dumped, traded, or recycled under inferior conditions (Baldé *et al.*, 2017).

While Europe is currently the largest generator of e-waste per inhabitant (16.2 kg/inh/year), it is also the region with the highest e-waste collection rate (42.5%) in the world (Forti *et al.*, 2020).

E-waste may contain hazardous substances and hence its transboundary movements are regulated by the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, to which 188 States are parties as of May 2021. In 2019, the Ban Amendment entered into force, effectively prohibiting the export of hazardous wastes (including e-waste) from developed to developing countries. While the Convention was designed to control trade in hazardous and other wastes, it does not apply to used, fully functioning electronic products. However, it may be difficult to draw a distinction between used and near-to-end-of-life electronics and e-waste. E-waste mislabelled as used electronics can still be shipped illegally from regions generating relatively large amounts of e-waste, such as North America and Western Europe, to countries where the e-waste can then be processed or dumped, such as in Brazil, Mexico, Ghana and Nigeria (WEF, 2019). Exported e-waste can either be knowingly (and sometimes illegally) exported as used electronics, or can be damaged in transit and become e-waste due to a lack of proper protection. Countries receiving e-waste often do not have appropriate legislation and the capacity for appropriate e-waste collection, treatment and disposal, creating a variety of adverse impacts on the environment and health of the (often informal) workers and the local population. The illegal traffic of e-waste is a crime that has serious impacts on the environment globally (UNEP, 2018).

2.3 Chemicals of concern (CoC) and electronics

Electronic equipment is made of a variety of components and materials, which are in turn composed of various chemicals and elements. More than 500 chemicals have been identified for use in the manufacture of electronic components, such as plating chemicals, cleaners, solvents, polymers and their additives, solders and specialty gases (OECD, 2010). While not all chemicals used in electronics production are retained in the final product, 162 chemicals have been identified as requiring a material composition declaration of electronic products (IEC, 2021). Since material and chemical formulations used in electronics are constantly changing, due to the sector's rapid innovation and the requirements relating to product appearance and functionality, obtaining up-to-date and detailed information about chemical uses is a challenge, as the flow of information through the complex electronics value chain is often disrupted. The Strategic Approach to International Chemicals Management (SAICM), a global, multisectoral and multi-stakeholder policy framework to promote chemical safety around the world, has identified transparency of information on chemicals in global supply chains and the use of hazardous substances within the EEE life cycle as emerging policy issues.

Some chemicals used in electronics are hazardous, such as carcinogens, mutagens and endocrine disruptive chemicals (EDCs) and can harm human health and the environment if the equipment and resulting e-waste are not handled properly. Prominent examples of such CoC are toxic metals, including mercury, lead, cadmium, chromium, certain halogenated and nonhalogenated flame retardants and certain phthalates (Blum *et al.*, 2019; Ilankoon *et al.*, 2018; Kousaiti *et al.*, 2020; UNEP, 2013). Certain chemicals are associated with an electronic product's specific applications and components. These chemicals include polybrominated diphenyl ethers (PBDEs), some of which are persistent organic pollutants regulated by the Stockholm Convention on Persistent Organic Pollutants, and which have been commonly used in a wide range of electronics as flame retardants to reduce the risk of fire in plastic components. Likewise, mercury is an essential component in fluorescent light bulbs, while lead is used in lead-acid batteries. Finally, polychlorinated biphenyls (PCBs) have been used in electric transformers and capacitors and, while PCBs are listed among the 12 initial persistent organic pollutants under the Stockholm Convention, they are still in use in many parts of the world, including Africa (GEF, 2016). While CoC can be present in a variety of electronic products, unbranded, inexpensive products (particularly in developing markets) may be more likely to contain CoC, be mislabelled or be poorly documented (KEMI, 2016).

In addition to the risks to human health and the environment, the presence of CoC in products, including electronics, poses a threat to the concept of the circular economy, hampering the EoU processing of electronic products, and limiting the recyclability of materials, thereby reducing the potential to close material loops (Pivnenko and Astrup, 2016). This means that recycled materials containing CoC cannot be used in production due to specific quality restrictions, on food packaging or toys, for example, or due to general restriction and prohibitions. If restricted CoC are not removed from products during recycling, this can result in "legacy contamination" of recycled material flows, as has been illustrated using the example of flame retardants in plastics (Pivnenko *et al.*, 2017).

Instead of using CoC in electronics, less problematic chemicals can potentially be used as substitutes offering the same or similar function in a product or process. This requires integrating relevant criteria into the product design process, and potentially altering the manufacturing process or product configuration, to avoid, or significantly reduce, the use of CoC in electronics. While informed substitution is a critical chemical risk management approach used by companies and countries (UNEP, 2019b) and, while guidance does exist on the minimum requirements for determining suitable chemical alternatives (OECD, 2021), effective chemical substitution remains a complex, unresolved issue, even in places with the most advanced chemical legislations, such as the EU (PNO, 2019).

Finally, improper handling of e-waste can also release or even generate CoC. For example, chlorofluorocarbon (CFC) gases released due to the improper treatment of temperature exchange equipment, or the formation of chlorinated dioxins and furans (one of the most toxic synthetic chemicals produced) due to uncontrolled incineration and the open burning of wires and cables containing PVC insulation. Informal e-waste treatment and recycling have been associated with the significant release of CoC and increased environmental pollution (Sepúlveda *et al.*, 2010).

The use of certain CoC in products is in fact subject to regulatory frameworks, information requirements and restrictions such as the EU's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation. Specifically for electronics, the EU's Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS, Directive 2011/65/EU) and its subsequent revisions are among the key substance-specific policy instruments used in the EU and replicated (with or without adjustments) in many countries and regions throughout the world (UNEP, 2020). The original legislation came into force in 2003 and has been continuously updated as new information becomes available, with the latest proposal for a review expected in 2021. Most developing countries, particularly in Africa, lack substance-specific provisions such as those of the RoHS, to restrict the use of certain hazardous substances in electronics (UNEP, 2020).

2.4 Sustainability hotspots in the electronics value chain

Hotspot analysis has been used extensively in the sustainability context, to provide an overview of the areas where designed actions can be most effective and resource efficient. Focusing on a product life cycle, or a complete value chain, hotspot analysis highlights priority issues, and the right life cycle stages and actors within the value chain. It does not substitute a detailed analysis of all life cycle stages, such as a life cycle assessment, but helps to identify key areas of concern and to develop and prioritize appropriate actions. While there is no common, generally recognized hotspot analysis methodology, the UNEP/SETAC Life Cycle Initiative has provided a methodological framework for assessing life cycle impacts (UNEP/SETAC, 2017). While the proposed framework suggests a comprehensive and iterative process, in the present report, the goal of the hotspot analysis is to identify relevant hotspots in the electronics sector and, combined with the information provided in Sections 3.1-3.3, support specific recommendations along the electronics value chain for Africa in Section 3.4.

Environmental hotspots for electronics differ depending on equipment type and use. For example, most emissions for a typical washing machine or a tumble dryer occur in use, while for mobile phones, the extraction of raw materials and production are most critical (EEA, 2020). It has been suggested that the use phase can be the life cycle stage with the most environmental impacts (Subramanian and Yung, 2016), particularly for energy-intensive devices and applications, as illustrated using the example of carbon emission flows of blockchain operation in China (Jiang *et al.*, 2021). However, such conclusions greatly depend on assumptions, particularly in relation to the emission intensity of electricity production sources (coal, crude oil, natural gas or renewables). Similarly, while transportation can contribute significantly to the climate impacts of an electronic product, these impacts also vary considerably depending on the mode of transport used (air, road, rail or sea) and the distance a product is transported. Nevertheless, hotspots relevant to most types of electronic equipment can be identified across the sector, with Table 2.1 providing an overview of the hotspots associated with the electronics value chain. Since most features of an electronic product are established in the design phase, the majority of the environmental, as well as social and economic impacts, are associated with design. This stage includes choosing the materials and chemicals to be used, how long a product can be used for and how easily it can be repaired, disassembled and finally recycled. The environmental impacts of materials and processes are often poorly considered during this phase.

Across the sector, the main environmental hotspots relate to the extraction and refinement of raw materials, to production, and to the EoL stages. About half of global greenhouse gas (GHG) emissions, as well as 90% of biodiversity loss and water stress are associated with the extraction and processing of natural resources (IRP, 2019), of which metals and fossil fuels are extensively used in electronics production. In Africa, mining activities, a source of many of the metals, including cobalt and platinum, used in electronics manufacturing are also associated with the substantial use of water and land, and the degradation of local ecosystems (Edwards *et al.*, 2014). Some electronics manufacturing processes, for example, to make semiconductors, which are commonly used in data processing, storage and communication within an integrated circuit and in related high-tech industries, are considered water-intensive (Den *et al.*, 2018) and can result in surface and groundwater pollution due to the production of wastewater discharges (Abdel Wahaab and Alseroury, 2019; Hsu *et al.*, 2011; Lin *et al.*, 2009). It takes 7,500 litres of water to create a single integrated circuit on a 30 cm wafer, the average smartphone having a water footprint of more than 12,000 litres (Burley, 2015; CWR, 2013). The improper treatment of e-waste leads to a variety of environmental impacts, including CO2 and CFC air emissions, for example, the uncontrolled dismantling of a refrigerator releases four times more CO2 equivalent than a controlled process (Safaei and *et al.*, 2018). Improper treatment also contaminates receiving water bodies, soils, resulting in biodiversity loss. In addition, CO2 emissions result from the incineration of electronics plastic parts, made predominantly from fossil fuels and accounting for between 10% and 30% of the electronic product weight (Maisel *et al.*, 2020). In many developing countries, rudimental recycling, such as open burning of e-waste to separate metals from organic chemical fraction, such as copper from plastic coating in wires, causes the release of dioxins, mercury, formaldehyde and other pollutants to atmosphere, affecting air quality (Safaei and *et al.*, 2018). Likewise, the use of acid baths[2] to leach precious metals from printed circuit boards causes air and water pollution.

When considering the social impacts of the electronics value chain, a variety of concerns are associated with the lack of transparency, appropriate regulations, controls and limited due diligence in the global supply chain (Gonzalez *et al.*, 2020). It is also crucial to consider health considerations, related to the use of CoC in products, usually defined in the design phase, the electronic product manufacturing processes (Kim *et al.*, 2014), and raw material extraction and refinement. Large amounts of minerals and metals, such as gold, tantalum and tin, used in the electronics industry come from artisanal and small-scale mining (ASM), where workers can be frequently exposed to mercury, zinc vapor, cyanide and other acids (IGF, 2018). It has been reported that child labour is widespread in such informal mining activities (African Resources Watch and Amnesty International, 2016) and women in sub-Saharan Africa bear most of the risks associated with mercury emissions resulting from ASM (IGF, 2018). This is particularly pronounced in conflict areas, where illegal, labour-intensive activities are carried out with little concern for safety or health standards. In addition, emissions resulting from the improper management of e-waste , predominantly by the informal sector, involve risk for people engaged in the work and adverse effects on the local community (Orisakwe *et al.*, 2019). In developing countries, the informal sector dominates the EoL value chain and material flows of waste electronics (ILO, 2014). The effects of exposure to e-waste and its worst practices, such as open burning and acid bath leaching, are not completely understood, but may include cancer and negative effects on reproductive, cardiovascular and immune systems, changes in lung function, thyroid function, hormone expression, birth weight, birth outcomes, childhood growth rates, mental health, cognitive development, cytotoxicity, and genotoxicity (Perkins *et al.*, 2014; UNEP, 2019b). The social risks of informal e-waste processing primarily involve poor labour conditions and child labour, excessive working hours, elevated risks of injury and stress, and a lack of labour rights (Burns *et al.*, 2019; Ekener-Petersen and Finnveden, 2013). E-waste management in developing countries is often done by the informal sector, providing livelihood opportunities to a large number of people. Furthermore, in developing countries, the informal recycling of electronics has traditionally been practised by marginalized groups who are often subject to harassment by the authorities and police (Nzeadibe and Iwuoha, 2008). Consideration must also be given to the limited transparency in raw material sourcing and risk of corruption, as illustrated in the illegal trade of e-waste (Huisman *et al.*, 2015).

Finally, the economic hotspots relate primarily to the loss of economic value embedded in materials and resources, resource scarcity and security of supply. The raw materials present in the global e-waste flows have been valued at around 57 billion dollars (which is larger than most African countries' gross domestic product (GDP)) and, as the majority of global e-waste is not properly managed or documented, it is safe to assume that most of this value from materials is currently lost (Forti *et al.*, 2020). The theft of and illegal trade in e-waste can also be considered a value loss for society and have been pointed out as a hotspot in the electronics EoL value chain in the EU (Huisman *et al.*, 2015). The externalization of environmental and social costs through non-compliant e-waste management, both formal and informal, creates an environment of unfair competition and increases e-waste processing costs for compliant entities, resulting in economic value loss. Appropriate material recycling and recovery are further hindered, as the design phase focuses on product design, including on choice of material, colour and shape and on short product life cycles. If properly recycled, e-waste could contribute to fulfilling the need for raw materials, rather than depleting the world's non-renewable resource reserves. The concentration in e-waste of certain precious metals is much higher than in metal ore; there is, for example, a hundred times more gold in a tonne of waste mobile phones than in a tonne of gold ore (Smedley, 2020). Finally, many of the minerals and metals, including cobalt, Platinum Group Metals (PGM) and Lithium, used in the electronics sector are considered critical, as these elements play a key role in electronics supply chains, renewable energy technologies, defence equipment and strategic reserves, while their production is concentrated and their supply prone to disruption (EC, 2017).

2 A hazardous wet chemical leaching process where e-waste goes through a series of acid (e.g., using sulfuric acid or aqua regia) or caustic leaches to separate a soluble component (e.g., copper, gold, silver) from a solid.

Table 2.1. Overview of hotspots detailing the adverse impact on sustainability in different stages of the global electronics value chain.

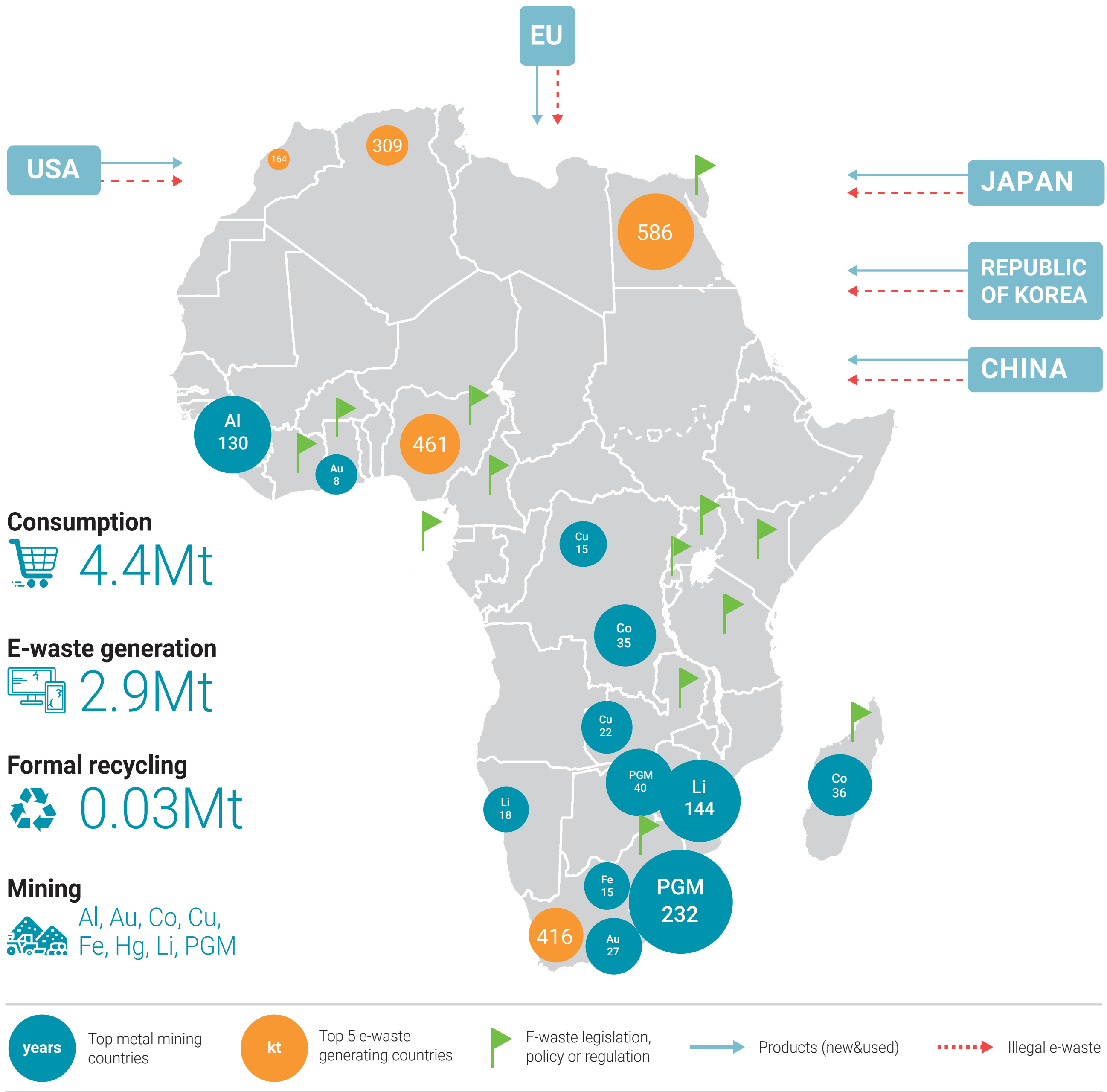
	IMPACT AREAS	RAW MATERIALS	PRODUCTION	CONSUMPTION	END-OF-LIFE
ENVIRONMENTAL	**Climate**	Combustion of fossil fuels for extraction and processing of metals and fossil fuels used for plastic production	Combustion of fossil fuels used as energy sources in production; transportation of raw materials and products	Emissions from electricity used in equipment lifespan, product distribution and transport	Incineration of waste plastic results in direct CO_2 emissions; CFC and HCFC gases released due to improper treatment of temperature exchange equipment
	Water	Use and contamination of fresh water in material extraction and refining	Some manufacturing processes (e.g., semiconductor) are water-intensive, and release pollutants in water if discharged without pre-treatment		Contamination of surface and groundwater due to improper waste management
	Land	Land use for raw material mining and extraction; deforestation and soil contamination			Land used for e-waste or its residue disposal; soil contamination
	Ecosystem	Ecosystem disruption due to mining and exploration; impact on biodiversity	Impact of wastewater discharges from production on surface and groundwater ecosystems		Toxic emissions (air, water and soil); resulting contamination of surrounding environment; impact on biodiversity
	Resources	Use of primary non-energy related and fossil (non-renewable) resources	Use of fossil (non-renewable) energy sources	Use of fossil (non-renewable) energy sources	Non-recovery of secondary materials contributes to resource depletion
SOCIAL	**Human health**	Exposure to CoC used in material extraction due to low-tech; informal sector in raw material extraction	Excess health risks due to exposure to CoC in electronics production and repairs		Risk of injury and exposure to hazardous and toxic chemicals from informal recycling; lack of safe and healthy living conditions for local communities
	Social risks	Risk of child labour, excessive working hours, lack of social security and occupational protection; vulnerable population most affected; use of conflict minerals	Excessive working hours, lack of social security and occupational protection		Risk of child labour, excessive working hours, lack of social security and occupational protection; vulnerable population most affected; loss of livelihood when informal e-waste treatment is phased out
	Governance risks	Risk of corruption; limited transparency		Product choice and use; behaviour when disposing of EoL electronics	Risk of corruption; limited transparency, illegal traffic and environmental crimes
ECONOMIC	**Value loss**			Electronic products with short lifespan	Components, materials and resources lost when waste is dumped, landfilled or incinerated; theft of and illegal trade in e-waste; unfair competition due to non-compliant competitors managing e-waste
	Resource scarcity and security of supply	Concentrated supply of critical raw materials limited to few countries			Non-recycling of waste materials leads to lower resilience in raw material supply chains. Limited transparency and traceability

3.
THE ELECTRONICS VALUE CHAIN IN AFRICA

3.1 Mapping regional flows

Figure 3.1 illustrates the key information presented in sub-Section 3.1. Africa is a major mining source of aluminium, gold, cobalt, copper, iron, mercury, lithium and platinum which are major elements used in electronics production. Raw materials for electronics production are exported from Africa, converted into products elsewhere in the world and then some are imported into Africa. In 2019, 4.4 Megatons (Mt) of electronics were put on the African market (Forti, 2020), China and the EU being the major exporters of electronic products to Africa. In the same year, 2.9 Mt of e-waste was generated, of which only 0.03 Mt were documented for collection and recycling (Forti, 2020). Most of Africa's e-waste is collected and treated informally. Thirteen African countries have established e-waste legislation, policies or regulations (Forti, 2020). The following sub-sections provide a brief overview of raw material extraction in Africa as part of the electronics supply chain (3.1.1), the production of electronics in Africa (3.1.2), the trade of electronics (3.1.3), electronics consumption, use and reuse (3.1.4) and e-waste generation and management (3.1.5).

Figure 3.1. Key information on the electronics value chain in Africa*.



* Estimates of metal supply horizons are based on mining production in 2018 for the countries identified in Table 3.1, and national reserves as estimated in USGS, 2020.

3.1.1 Raw material extraction

Many key minerals used in global electronics production are mined in Africa, and African countries are among the ten largest mining countries globally for aluminium, gold, cobalt, copper, iron, lithium, mercury and PGM (see Table 3.1). Many African countries' economies rely heavily on the mining sector (ICMM, 2018), a large share of their exports going to China, where most electronics production is concentrated (Dahir, 2019). Supply horizons for many critical metals in the region differ from metal to metal and from country to country. For example, considering current mining amounts and available reserves, gold mining in Ghana can last for eight years, while mining for PGM in South Africa can last more than two centuries (see Figure 3.1).

Africa has the highest population share depending on ASM for minerals, with more than 50 million people whose livelihood depends on the sector (IGF, 2018). Depending on the source of the estimates, the actual number of people relying on the sector might be significantly higher, although data availability and consistency is poor. While ASM is characterized by the number of miners involved, size of production, level of mechanization and level of capital investment, ASM activity in Africa is often informal and mostly operates illegally (IGF, 2018). ASM activities in Africa are also associated with negative environmental impacts, health and safety risks, child labour and human rights abuses (African Resources Watch and Amnesty International, 2016; IGF, 2018). While ASM is believed to responsible for the mining of more than 30 different minerals (Veiga *et al.*, 2014), the majority of ASM activities in Africa are concentrated on high-value minerals, like gold, as well as cobalt and copper (Sanderson, 2019; Whitehouse, 2019).

Table 3.1. Overview of key metals used in electronics. Key elements considered in the electronics sector: lead and lithium (Forti *et al.*, 2020); world mineral production for 2018 from Brown *et al.*, 2020.

Metal name	Symbol	TYPICAL APPLICATIONS	Top 10 global producers in Africa (WORLD ranking)
Aluminum	Al	Wiring, capacitors, heatsinks	Guinea (3)[1]
Antimony	Sb	Flame retardants and semiconductors	-
Bismuth	Bi	Semiconductors and solders	-
Cobalt	Co	Rechargeable batteries, integrated circuits and semiconductors	Democratic Republic of the Congo (1), Madagascar (10)
Copper	Cu	Wiring, motors and contacts	Democratic Republic of the Congo (5), Zambia (7)
Germanium	Ge	Semiconductors and solar cells	-
Gold	Au	Electroplated coating on connectors and contacts	Ghana (6), South Africa (10)
Indium	In	(Touch) screens, solar panels and semiconductors	-
Iron	Fe	Structural support and casing, motors, generators and transformers	South Africa (7)[2]
LEAD	Pb	Rechargeable batteries, solder, cathode ray tube (CRT)	-
Lithium	Li	Rechargeable batteries	Zimbabwe (5), Namibia (7)[3]
Mercury	Hg	Switches and fluorescent lights	Morocco (8)
Platinum group metals	Ir, Os, Pd, Pt, Rh, Ru	Hard disks (Pt, Ir), contacts (Os), conductive paste and plating (Pd), electroplated coating (Rh), screens (Ru)	South Africa (1), Zimbabwe (3)
Silver	Ag	Contacts and silver-based inks	-

[1]Bauxite; [2]Iron ore; [3]Lepidolite.

3.1.2 Production of new equipment

Compared to other regions, Africa has the lowest number of direct manufacturers of EEE and only a few local EEE assembly plants. These include a consumer electronics factory in Egypt owned by Samsung and a television assembly plant in South Africa owned by LG (ADBG, 2020). Such assembly plants manufacture products for the regional market, but their production volumes are significantly lower compared to direct imports from Asia. Reliable data on the domestic production of electronics is sparse and mathematical models have been used to fill in the data gaps

(Forti *et al.*, 2020). The limited production and assembly in the region is potentially related to the lack of necessary infrastructure and capacity, as well as competition from imports of low-cost electronics produced in industry hubs, such as China (see Section 1.2) or used equipment from domestic markets and international trade. Nevertheless, several countries in the region, such as Egypt and Morocco lead initiatives to promote innovation in the sector, increase domestic production and electronics exports, create jobs in the region and reduce import reliance (ITIDA, 2020; MCINET, 2021). Fuelled by rising demand for electronics in Africa and broader deglobalization trends in the global economy, further investment in and expansion of the regional production and manufacturing capacity are expected.

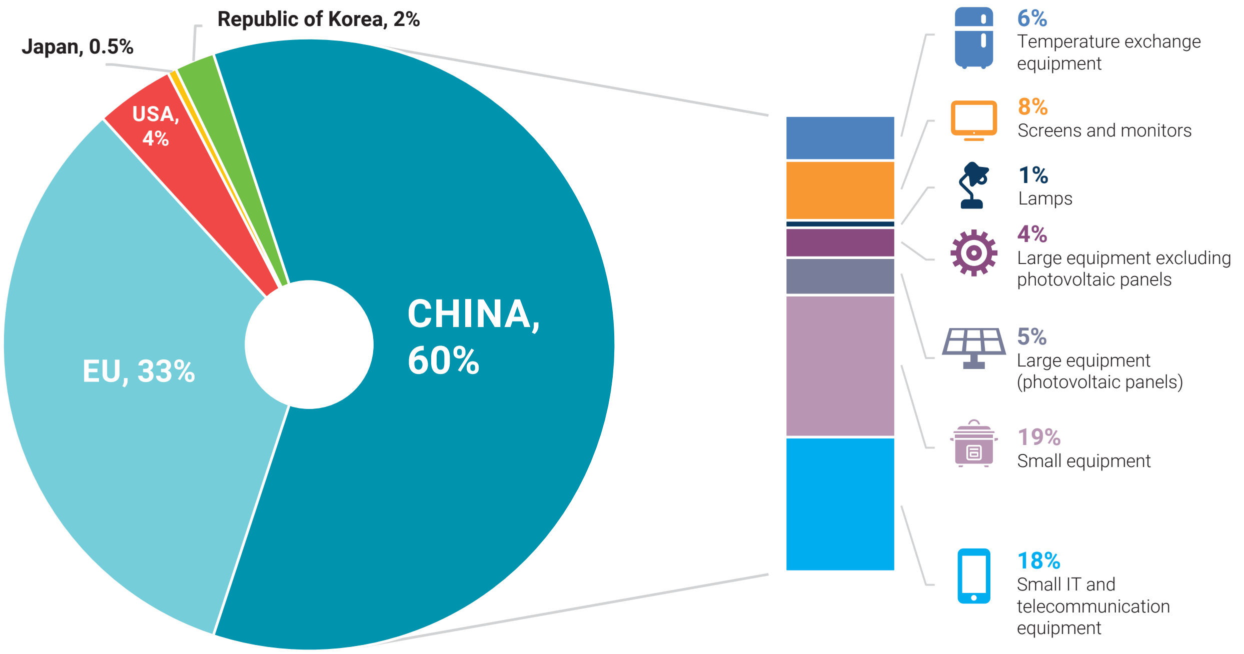
3.1.3 Import and export of new and used equipment

Most new EEE consumed in Africa is imported, since domestic production is very limited (see Section 3.1.2). Among the major global manufacturers, the majority of EEE is imported from China, followed by the EU and, to a much lesser degree, by the United States, the Republic of Korea and Japan (UN Comtrade, 2020). Most imports from China comprise small equipment and small IT equipment representing more than 60% of the import value (Figure 3.2). This is followed by screens and monitors (14%) and temperature exchange equipment (9%). Approximately 8% of the overall import value from China relates to solar energy, specifically, photovoltaic panels, which are expected to generate significant amounts of e-waste in need of effective collection and recycling in the future (Magalini *et al.*, 2016). Trade statistics do not distinguish between new and used equipment, so the data reported in Figure 3.2 represent a mix of new and used equipment. For examples of equipment included in each category see Table A.1 (Appendix A).

In higher-income countries, greater purchasing power and high labour and repair costs cause consumers to prefer new equipment, and the market value of used equipment to be relatively low. The reverse can be said of most African countries, namely, purchasing power and labour costs are lower, which creates favourable conditions for importing large amounts of used electronic equipment on an annual basis. Furthermore, imported used equipment from Europe or the United States is perceived to be of better quality and is often preferred to new, lower quality equipment (Bates and Osibanjo, 2020). Finally, fluctuations in national currencies, with respect to the US dollar, for example, or economic slowdowns, including the COVID-19-induced slowdown in 2020-2021, have produced a shift from new to second-hand, less expensive products.

Figure 3.2. Exports to Africa from the largest EEE manufacturing countries and regions and share of different EEE types exported from China, the largest trade partner, to Africa.

The shares represent the distribution of the trade value for 2018 in US dollars (trade statistics data source: UN Comtrade, 2020; considered HS codes are provided in Forti et al., 2018; the link between the UNU-Keys and EU classification of EEE under the six categories (EU-6) is provided in Forti *et al.*, 2020).



No official statistics on trade in used equipment are available and estimates of imported UEEE to Africa are sparse. For example, a field study of two main UEEE import hubs in Nigeria estimated UEEE imports to be between 60,000 and 71,000 tonnes per year, which corresponds to approximately 10% of the annual amount of electronics put on the Nigerian market. EU countries, such as Germany and Belgium, and the UK, were found to be the main exporters, followed by China and the United States, with much smaller shares (Odeyingbo *et al.*, 2017). The share of used equipment in electronics imports may also depend on equipment type. For example, between 2010 and 2014, most (more than 60%) imported air conditioners, radios, refrigerators and stereos into Ghana were used (Oteng-Ababio *et al.*, 2020). However, for refrigerators, the share of new equipment has dominated imports since 2013, due to import restrictions and the implementation of energy efficiency standards (Ghana Energy Commission, 2019). Similarly, according to the Ghana customs office, of the total equipment imported between 2010 and 2014, only 8% of PCs and 1% of mobile phones were used (Oteng-Ababio *et al.*, 2020). Over the same period, most new appliances were imported from Asia, predominantly from China, while most used appliances came from Europe (Asante *et al.*, 2019).

While reusing EEE extends product lifespan, imported used products might be damaged or outdated, resulting in lower subsequent lifespans for these second-hand products. Out of approximately 71,000 tonnes of UEEE imported into Nigeria, at least 19% was non-functional[3] on arrival, depending on UEEE type and ranging from 5% for pressing irons and photocopiers to 55% for LCD televisions (Odeyingbo *et al.*, 2017). Since the functionality tests were rather basic, the actual share of faulty equipment among UEEE imports is likely to be even higher. To tackle this issue, several African countries have imposed or are imposing stricter control, restriction or an outright ban on imports of certain types of EEE (Danish EPA, 2015; Paben, 2019). Current prohibitions or restrictions on the trade of hazardous and other wastes (including e-waste) by parties to the Basel Convention are available online[4].

3.1.4 Consumption, use and reuse

Electronics consumption in Africa is growing. In 2019, 4.4 Mt of EEE, including new and used products, was put on the market in Africa (Forti *et al.*, 2020). There was a significant increase (24%) between 2015 and 2019, second only to the increase in electronics consumption in Asia during the same period. Roughly half of this increase can be attributed to population growth, since EEE put on the market per capita went up from 3.4 kg to 3.8 kg (i.e., a 12% increase) during the period.

Most EEE was imported for consumption, while only a fraction is expected to be domestically produced. Second-hand electronics markets are common in most countries and are especially large in developing countries. Used, repaired and refurbished equipment is either imported as it is or repaired and refurbished in a country in the region. While precise quantitative data on the extent of reuse is unavailable, it is likely to represent a large proportion of the electronics market in Africa. It was estimated that Ghana had 1,200 EEE repairers, primarily situated in Greater Accra and not registered as business entities (Amoyaw-Osei *et al.*, 2011). The reuse of electronics also extends to product components, such as spare parts used in repairs, which are often harvested from old devices (Groscurth *et al.*, 2020). The repair and refurbishing sector is characterized by a low degree of formal training and provides many with an income, involving more than 30,000 people in Accra (Ghana) and Lagos (Nigeria) (Schluep *et al.*, 2012).

Africa has the fastest growing population, with that of sub-Saharan Africa expected to double and account for more than half of global population growth by 2050 (UN, 2019). As a result of an increasing urbanization, economic development and cultural changes, combined with growing electrification and connectivity, the rising population can be expected to create a significant increase in electronics consumption in the region. Furthermore, the lack of minimum standards on electronics energy efficiency and the expected consumption increase could have an adverse impact on electricity consumption in the region, with sub-Saharan Africa already considered the most energy-intensive region in the world (IEA *et al.*, 2020).

3 The basic functionality test included switching a device on and testing its basic functioning, e.g., the heating of an iron, a television turning on and a refrigerator compressor starting.

4 http://www.basel.int/Countries/ImportExportRestrictions/tabid/4835/Default.aspx

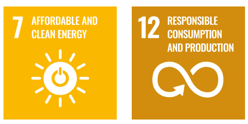
Box 1. Off-grid solar system solutions

In many African countries, electrification rates are relatively slow and are outpaced by population growth, particularly in sub-Saharan Africa. To help solve this issue, off-grid, renewable-energy-based solutions are being used. This is a rapidly growing area, with off-grid solutions providing a basic electricity service to 136 million people in 2018 globally, compared to only 1 million people in 2010 (IEA et al., 2020). However, high the purchase costs for such equipment are a limiting factor for many, especially in rural areas where access to electricity is most limited.

As a potential solution, private companies make the necessary investment and provide small off-grid systems as a service, or lease the systems to customers. Such systems usually use solar energy as the electricity source and include photovoltaic panel storage units (i.e., batteries) and peripherals linking and controlling the system. In addition, many providers offer a set of complete systems, where selected types of electronic equipment, such as lights, televisions, radios, fans, refrigeration units and solar water pumps are also included. These systems are often offered as a service on a "pay-as-you-go" basis or ownership is progressively transferred to customers after a certain time period ("lease-to-own"). Pay-as-you-go is a major driver in the growth of the global off-grid solar sector, which is expected to increase further (IFC, 2020). East Africa is the leading region, where millions of people are benefiting from off-grid solar systems (GOGLA, 2020).

In addition to providing electricity to people most in need, such systems have an impact on the electronics value chain. Electronic products are designed considering local conditions, and ownership of the system (and the electronic products it contains) is often retained by the formal service provider. This creates an incentive for better product design and more efficient asset management, where products are longer lasting, more durable, and easier to upgrade and repair. Even if product ownership is transferred to a consumer, they are more likely to seek information for appropriate disposal of their e-waste devices (REWMOS, 2018). The resulting e-waste is more likely to be formally collected and appropriately recycled. Finally, off-grid solar is expected to support 1.3 million full-time jobs by 2022 (IFC, 2020).

Primary barriers faced by such schemes are associated with financial sustainability, as service providers usually cover the upfront capital costs for the customer, and cheaper, poor-quality products, usually from China, are undercutting the higher quality products on the market. Furthermore, service providers often struggle to understand customer credit profiles, which can lead to high default rates and losses. The greatest need for off-grid solar systems in Africa is in rural areas, where creating a distribution network and the reverse logistics for the recycling of EoL off-grid systems is challenging. However, a voluntary EPR approach is promoted among the members of the off-grid solar industry association and stronger customer-business relationships have been leveraged for better e-waste collection and management (GOGLA, 2019).

The challenge	Rural sub-Saharan Africa lacks access to electricity, with poor grid coverage and significant blackouts. The affected population does not have the funds to upgrade or extend such expensive and complex systems of national infrastructure
The solution	Small off-grid systems or mini-grids, often based on renewable energy sources such as solar, can be used. Many companies offer a tiered set of connected appliances, including lights, radios, televisions and fridges, in addition to the pay-as-you-go energy service, complementing the electricity generating system
The benefits	1. Access to affordable, reliable and sustainable electricity 2. Electronic products and system configurations are often designed considering local conditions 3. Procurement, installation, servicing, reuse and e-waste management are done by a formal, centralized entity 4. Local jobs are created, including in product repair, refurbishing, reuse and e-waste management
What makes it circular?	Product-as-a-service increases electronic product lifespan and creates incentives for formal repair and reuse. Centralized ownership of products improves formal e-waste collection and recycling, resulting in more materials being maintained in material loops for longer
What are the main barriers?	1. Financial sustainability due to narrow profit margins, high upfront costs for service providers and market competition from poor quality products 2. High risks associated with a lack of detailed knowledge of customer credit profile 3. Challenging delivery, installation and maintenance in rural areas 4. Lack of functional EPR schemes and formal collection and recycling infrastructure
Main lifecycle stages	• Design • Consumption/Distribution • Maintenance (service, repair and reuse) • EoL (collection)
SDGs	

3.1.5 E-waste generation and management

3.1.5.1 Generation

In 2019, some 2.9 Mt of e-waste was generated in Africa, representing 2.5 kg of e-waste per capita in a year (Forti *et al.*, 2020). This represents a significant increase in the amount of e-waste reported in 2014 and 2016, which stood respectively at 1.9 Mt and 2.2 Mt (Baldé *et al.*, 2017, 2015). According to Global E-waste Monitor data (Forti *et al.*, 2020), the countries generating the largest amounts of e-waste are Egypt, Nigeria, South Africa, Algeria and Morocco, together responsible for almost 70% of the e-waste in Africa. Per capita generation varies significantly in the region, from 0.5 kg per capita for Burundi, the Central African Republic, Guinea-Bissau, Malawi, Mozambique, Niger and Sierra Leone to more than 10 kg per capita for Libya, Mauritius and Seychelles. However, these amounts are significantly lower compared to average e-waste generation in Europe (16.2 kg per capita) or the Americas (13.3 kg per capita). The estimates of e-waste generated in the region do not include the amounts of e-waste illegally imported, quantitative estimates of which are lacking (see Section 3.1.5.2). Increasing overall volumes of e-waste in the region, whether generated domestically or imported, is a cause of concern for most African countries, since the development of infrastructure for environmentally sound e-waste management is lagging behind, thereby diverting more materials to suboptimal treatment by the informal sector.

3.1.5.2 E-waste trade

While trade in used electronics may bring significant benefits to many countries in Africa, due to the lack of a harmonized definition of waste, as well as bureaucracy and corruption, the Basel Convention and national regulations are often infringed, and significant amounts of e-waste end up being imported into Africa having been declared as used EEE (Odeyingbo *et al.*, 2017). While there is no reliable data on the exact amounts of e-waste being imported into Africa, the amounts illegally imported from Europe, North America and Asia are considered to be significant (Forti *et al.*, 2020). For example, up to 10% of e-waste generated in the EU has been thought to be illegally exported, much of it possibly ending up in Africa.

Most international movement of e-waste has been considered to be southbound, that is, moving from the global north to global south. However, the lack of effective dismantling and recycling infrastructure in Africa may result in the shipment of valuable e-waste fractions from Africa to the northern hemisphere or to China for processing and recycling. For example, printed circuit boards, containing precious metals, such as gold and silver, as well as copper, lead and aluminium, may be shipped from Ghana, Tanzania and Nigeria to Europe or Asia for recycling (Forti *et al.*, 2020).

3.1.5.3 Informal collection and recycling

Since full-scale take-back systems and formal collection schemes for e-waste are limited in Africa, only small-scale projects with a limited capacity, or pilot projects are currently implemented. These projects include the WEEECAM project in Cameroon, supported by the French Facility for Global Environment, the MESTI-PIU projects in Ghana, supported by the German Corporation for International Cooperation, and the EPR project in Nigeria, supported by UNEP. This means that most generated e-waste is collected informally, either directly from the source of the e-waste generation or at waste dumps. For example, at the Agbogbloshie site in Ghana, considered to be one of the largest e-waste dumps in the world, more than 5,000 scrap workers operate daily collecting e-waste and either dismantling it on the spot or transporting it to private backyards, where dismantling and recovery of valuable materials may occur (Forti *et al.*, 2020). Similarly, in Nigeria up to 100,000 people work within the informal electronic waste sector (ILO, 2019). Such operations are performed in suboptimal conditions, where electronic boards are manually stripped for resale, wires and components are burned in the open air to recover metals, such as copper and iron, and the residual, low value fraction, containing plastic, glass and ceramics, for example, is simply discarded. Such practices are associated with extensive environmental pollution, the exposure of scrap workers to CoC, including mercury, certain FRs, and certain phthalates, injuries and the suboptimal recovery of recyclable materials. While informal collectors and recyclers may be aware of some of the hazards associated with their activities, most exhibit a degree of resistance towards being part of a formal entity (Soliman and Boushra, 2017). Finally, informal e-waste collection and recycling has a high risk of using child labour and is highly gendered, where men dominate most activities, while women are restricted to less physical, lower-paid, irregular activities, such selling tools or food to the informal metal scavengers, e-waste collectors and recyclers (Oteng-Ababio, 2018).

3.1.5.4 Formal collection and recycling

In Africa, 26,000 tonnes of e-waste were reported to have been formally collected and recycled in 2019, accounting for less than 1% of the e-waste generated in the same period (Forti *et al.*, 2020). While formal collection and recycling of e-waste in Africa is in its infancy, countries such as South Africa, Ghana, Nigeria, Egypt, Kenya, Morocco, Namibia and Rwanda have established formal e-waste collection and treatment facilities. For example, through public-private partnerships (PPPs), Rwanda has recently built a 10,000 tonne-capacity recycling plant that theoretically can treat the majority of e-waste generated in the country (Nkurunziza, 2020). Similarly, Nigeria has established and is gradually expanding its e-waste collection and treatment capacity. NGOs are supporting the expansion of e-waste collection in Ghana, including Caritas Ghana, with its campaign, “Care for Our Common Home” (Caritas Ghana, 2018). Pioneering formal recyclers in the country can also cover a large variety of e-waste and even employ a mobile degassing unit for the pre-treatment of refrigerators and air conditioners. In most cases, the pre-treatment capacity of formal recyclers is limited to manual disassembly and simple volume reduction, such as shredding, before e-waste components are shipped for recycling abroad to, among others, the Gulf states, China or the EU (Magalini *et al.*, 2020).

However, the dominance of the informal sector and its lower associated costs, due to non-existing standards and suboptimal practices, and the fact the informal sector cherry-picks valuable e-waste fractions only, makes competition between formal facilities and the informal sector unfair and particularly challenging. Consequently, low amounts of e-waste are collected through formal methods, limiting the formal system's expansion, and the share of e-waste processed in accordance with the existing standards. This inability to organize functional e-waste collection, combined with the lack of a stable supply of e-waste for treatment, eventually results in an unsustainable future for existing facilities and hinders the establishment of new facilities.

3.1.5.5 Hazardous and special waste management

Chemicals of concern (CoC) can be present in electronics, particularly in low-priced electronic products, as suggested by a Swedish Chemicals Agency study (KEMI, 2016). Unable to recover value from most e-waste fractions containing CoC, these fractions are largely either ignored by informal recycling operators, dumped or openly burned, thereby contaminating local environments. Organized systems for the collection and management of hazardous e-waste fractions, particularly arising from households, are practically non-existent in Africa. Only a few types of formal hazardous waste collection exist in some countries in Africa, such as Kenya, Rwanda and South Africa, while treatment facilities are sparse and are limited to hazardous waste landfills, such as in Alexandria, Egypt. Most collected hazardous waste, including selected e-waste fractions, is exported for treatment and disposal. Selected e-waste hazardous fractions containing CoC in Africa include:

- Fluorescent lights containing mercury
- Plastics containing certain FRs deemed CoC
- Electric cable insulation containing PVC
- Electric transformers and capacitors containing PCB oils
- Compressors and insulation foams from temperature exchange equipment containing CFCs and HCFCs
- Cathode ray tube (CRT) containing leaded glass
- Batteries containing toxic metals and acids (e.g., lead-acid batteries)

Hazardous e-waste fractions of value, such as lead-acid batteries, can be sought after by recyclers, who either dismantle them or export them directly for recycling. Transboundary movement of hazardous wastes is regulated, globally and regionally, by the Basel Convention and by the Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa. Section 3.2 provides an overview of key international and regional processes governing the electronics sector and relevant CoC.

3.2 Key international and regional processes and agreements

In addition to developments in national legislation and regulations related to the electronics value chain (see Table 3.3 for selected country details), the issue of electronics in the region is governed by international and regional agreements. A brief overview of the selected key agreements, their main objectives and relevance to the electronics sector is provided in Table 3.2.

Table 3.2. Selected key International and regional agreements related to the electronics sector.

AGREEMENT	SCOPE	PURPOSE/OBJECTIVE	RELEVANCE
Basel Convention	International	Control of Transboundary Movements of Hazardous Wastes and their Disposal	Due to the potential presence of hazardous substances, e-waste is considered hazardous waste and all cross-border movements should be reported and approved
Bamako Convention	Regional	Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa	Prohibits imports of e-waste into Africa; minimizes and controls transboundary movement of e-waste within the region; prohibits incineration of hazardous waste; ensures "environmentally sound" e-waste management; promotes cleaner production and precautionary principles
Vienna Convention	International	Preserve human health, and protect the environment from any harmful effects of the depletion of the ozone layer	Encourages research activities, cooperation and the exchange of information between States, and national legislative measures related to ozone depletion (including CFCs and HCFCs)
Montreal Protocol	International	Regulates the production and consumption of ozone-depleting substances	Calls for a phase-down and ban of CFCs and HCFCs, previously extensively used in temperature exchange equipment (e.g., refrigerators, freezers and air conditioners)
Stockholm Convention	International	Protect human health and the environment from persistent organic pollutants (POPs)	Restricts and eliminates production and use of several POPs used in electronics (e.g., decaBDE, HBCDD); ensures "environmentally sound" management of e-wastes containing POPs; addresses unintentional POPs like dioxins and furans
Minamata Convention	International	Protect human health and the environment from the adverse effects of mercury	Restricts and phases-out uses of mercury through bans on new mercury mines and the phasing out of existing mines (including use of mercury in artisanal gold mining practised in Africa) and the use of mercury in electronics
Paris Agreement	International	Strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius	The production, use and EoL management of electronics can be associated with significant emissions of greenhouse gases (i.e., CO2 and CFCs)
African Ministerial Conference On The Environment (Amcen) Declaration	Regional	Presents key areas for a transition to a circular economy in Africa	Identifies electronics as one of the key sectors with opportunities for the circular economy in the region, specifically related to integrated e-waste management, product refurbishing, remanufacturing, recycling and material recovery

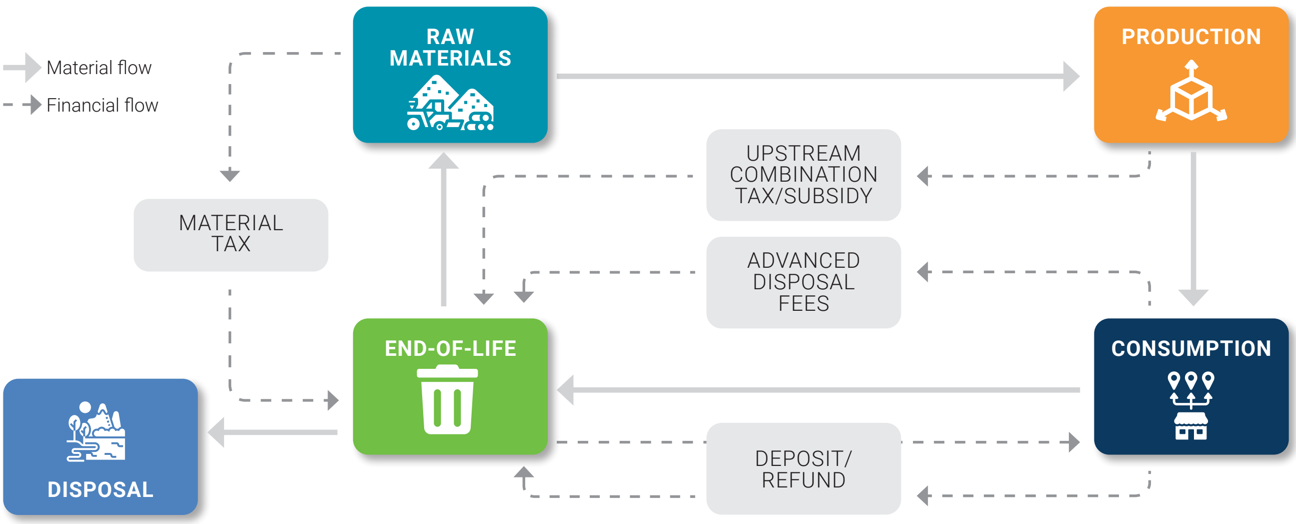
3.3 National extended producer responsibility (EPR) schemes

EPR is an environmental policy approach that builds on the polluter-pays principle. Under EPR, the producer's responsibility for a product is extended into a product's post-consumer stage, effectively involving producers in waste collection and sorting and the pre-treatment and recycling of products (OECD, 2016). While traditionally, EPR regulations have focused on the EoL stage and only indirectly addressed EoU products, EoU stages, including reuse and repair must be explicitly covered by EPR, with a view to its integration into the circular economy (Pouikli, 2020). The definition of the term "producer" in an EPR scheme is crucial to its implementation, as it has legal implications for the requirements and obligations of producers. If properly designed and implemented, EPR can boost resource efficiency and advance circular economy mechanisms, as stipulated by the European Resource Efficiency Platform (EC, 2014a):

"EPR establishes incentives for producers to move to better waste management solutions beyond the EoL of products, pushes product design, remanufacturing and recycling, and enables the take-up of resource efficient business models."

In practice, EPR schemes are enforced on producers, either by obliging them to provide the financial resources required for EoL (and sometimes EoU) product management, or engaging them directly in organizational and operational aspects. In the former case, as part of the EPR scheme, collective producer responsibility organizations (PROs) carry out take-back, collection, recycling and waste management activities on behalf of producers. The most common EPR instruments fall into four categories of economic and market-based instruments (Figure 3.3), which can be typically combined with regulatory requirements, such as on product take-back, performance standards, such as those relating to the recycled content in products, and information-based instruments, such as on product labelling.

Figure 3.3. Overview of different economic and market-based EPR instruments (adapted from (OECD, 2016)).



One of the objectives of EPR schemes is to internalize environmental costs throughout the product life cycle, incentivizing producers to re-design their products and packaging to extend the EoU phase for products and facilitate EoL management of products, by avoiding the use of hazardous or problematic chemicals, for example. While the benefits of EPR in reducing waste generation and increasing recycling have been documented, the impact of EPR on eco-design has been limited and is often blamed on the complexity of the electronics value chain (OECD, 2016).

While EPR can cover a variety of products, such as packaging, EoL vehicles and tyres, globally, electronics are covered by the majority of EPR policies. Worldwide, the number of EPR policies has grown. However, until recently, very little attention has been paid to EPR in Africa, namely, with regard to product take-back in an organized manner (OECD, 2015). So far, specific e-waste legislation, policies and regulations have been introduced in 13 out of 49 countries analysed in the region (Forti *et al.*, 2020). While there is no single country in Africa where EPR policy is fully in place, several countries, including Nigeria, Ghana, South Africa, Senegal, Côte d'Ivoire and Kenya, are in the process developing or adopting such policies. For example, Nigeria, the most populous country in Africa, has progressed towards establishing an EPR scheme and, following the adoption of a national environmental regulation, the country formed its E-waste Producer Responsibility Organisation Nigeria (EPRON) in 2018. EPRON is the first PRO for electronic waste in Nigeria, covering both producers of new and used EEE. In

2020, the Nigerian Government gazetted a detailed guidance document on the implementation of EPR, which stipulates the roles and responsibilities of relevant stakeholders along the electronics value chain and sets up concrete short, medium and long-term targets for e-waste collection and recycling. In South Africa, the legislative basis for EPR was established in 2008, and the regulations concerning EPR for electronics were issued in November 2020 and came into effect in May 2021. The EPR regulations in South Africa are divided between general regulations, regarding EPR schemes in the country (No. 1184) and sector-specific regulations, including EEE (No. 1185) and the lighting sector (No. 1186). The operational vacuum that previously existed was partially filled through voluntary initiatives driven by industry, such as Lightcycle SA, which voluntarily collects waste lighting equipment in South Africa.

Overall, establishing EPR schemes in developing countries can be challenging due to the illegal import of e-waste and large grey (or even black) markets for the electronic devices (Kiddee *et al.*, 2013). Table 3.3 provides an overview of illustrative cases of the development of EPR schemes for electronics in Africa.

Box 2. Closing the Loop – International business model towards global EPR for mobile/smart phones

The export of used electronic equipment from Europe, North America and Asia to Africa occurs in significant quantities every year. It has been estimated that 70% of used mobile phones for reuse end up in low-income countries (Benton et al., 2015), many of them in Africa. While such practices may contribute to prolonging the lifespan of mobile phones, due to initial re-use, subsequent repair and re-use, once such mobile phones can no longer be used, they become waste. Most of the countries receiving used electronic equipment have poor formal collection and e-waste management, resulting in e-waste dumping or suboptimal recycling by the informal sector, with limited recovery of resources.

Since EPR schemes in many African countries are in their infancy, resources for proper collection and recycling of e-waste are very limited. Inspired by the extension of EPR schemes worldwide, Closing the Loop is a for-profit organization that collects fee from businesses in Europe and Australia when they purchase new mobile phones or sell their used mobile phones for re-use. The collected fee, together with the revenue generated from selling recycled materials, is then used to recover EoL mobile phones in countries, such as Ghana, Nigeria and Cameroon and to ship them back to Europe for treatment by certified recyclers.

Promoted as "waste compensation", the service provided by Closing the Loop primarily avoids the negative impacts associated with the disposal and suboptimal treatment of waste mobile phones in Africa. It also offers potentially higher recovery efficiency for EoL treatment and recycling. Recycled materials, primarily metals like gold, palladium, silver and copper, are sold back to the market, partially avoiding the environmental impacts associated with primary raw material extraction. The scheme also leads to formal job creation and additional income for people in Africa, with more than 2,000 people involved. Approximately 3 million EoL mobile phones have been collected and recycled so far.

The main challenges faced by the company are regulatory and financial. Firstly, the fees collected by EPR schemes in Europe and Australia do not take into account the fact that some electronics are exported for re-use. Unable to access those funds, Closing the Loop has to charge companies higher fees in order to cover the cost of the recovery of EoL phones and their recycling. This prevents more rapid expansion of the scheme to other companies and countries. Secondly, the implementation of the Basel Convention, designed to prevent waste shipping from high to low-income countries (dumping), puts a heavy administrative burden on Closing the Loop. The process of declaring EoL mobile phone shipments from Africa to Europe is extremely complicated, resource-demanding and must be repeated either for each individual shipment or for a limited time period.

The challenge	The majority (70%) of reused mobile phones end up in countries with a lack of e-waste management and recycling infrastructure. Once the mobile phones become waste, they are recycled in suboptimal conditions or not recycled at all.
The solution	The business model under which consumers of new (or sellers of used) mobile phones in Europe pay a fee, used to recover waste mobile phones from countries with a lack of collection and recycling infrastructure. Recovered waste mobile phones are shipped back to Europe and recycled.
The benefits	1. Avoided emissions due to uncontrolled recycling or dumping of waste mobile phones 2. Higher recovery and recycling efficiency for waste mobile phones 3. Job creation for people recovering waste mobile phones in Africa
What makes it circular?	Higher efficiency of collection and recycling result in more materials being maintained in material loops for longer
What are the main barriers?	International shipping of electronic waste is highly regulated by the Basel Convention which, combined with bureaucracy and corruption in Africa, makes return shipping of waste mobile phones from Africa to Europe complicated and inefficient
Main lifecycle stages	• Consumption • EoL (collection) • EoL (recycling)
SDGs	17 PARTNERSHIPS FOR THE GOALS; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 8 DECENT WORK AND ECONOMIC GROWTH

Table 3.3. Overview of selected EPR-related policy for electronics in a number of African countries (partially based on the key elements that e-waste legislation or regulations must include (Forti *et al.*, 2020)).

SOUTH AFRICA	NIGERIA	GHANA	KENYA	RWANDA
Key EPR-related policy for electronics				
National environmental management: Waste Act	National Environmental (Electrical/Electronic Sector) Regulations	Hazardous and Electronic Waste Control and Management Act and Regulations	Environmental Management and Co-ordination (Extended Producer Responsibility) Regulations	Regulation governing e-waste management in Rwanda
Policy status				
Approved (2008)[1] General EPR (2020)[2,3]; EEE EPR (2020)[4]; Lighting EPR (2020)[5]	Approved (2011)[6] EPR Guidance (2020)[7]	Approved (2016)[8,9] EPA Technical Guidelines (2018)[10]	Draft (2020)[11]	Approved (2018)[12]
Does legislation effectively establish an EEE EPR?				
✔	✔		(✔)	
Clear description of the goals and targets for the legislation				
✔	✔		(✔)	✔
Specific, quantitative targets				
Collection and recycling of 36,000 t with an annual increase of 30% for the next five years for e-waste; product-specific collection, recovery and recycling targets for lighting waste for the next five years	Short: 300 t Medium: 0.5% of EEE POM Long: 6000 t or up to 5% of EEE POM			
Defined role of authorities (e.g., municipalities and government)				
	✔		(✔)	
Clear definition of responsibility for organizing the collection and recycling				
✔	✔		(✔)	✔
Clear definition of responsible for financing e-waste collection and recycling				
✔	✔	✔	(✔)	✔
Definition of e-waste and related products				
✔	✔	✔		✔
Product or e-waste categories covered				
Large (>100 cm), medium (between 50 and 100 cm), small equipment (<50 cm), non-portable batteries and lighting equipment	E-waste category 1-6 (relevant for medium and long-term targets)	Extensive list of equipment (HS code), including batteries and lighting (see Fifth Schedule for details)	Electrical and electronic equipment and batteries. No further details of specific product groups given	Small and large household appliances, IT and telecommunications equipment, consumer equipment, lighting, tools, toys, leisure and sports equipment, medical devices, monitoring and control instruments, automatic dispensers, batteries, security and military equipment, florescent tubes (see Annex 1 for details)

SOUTH AFRICA	NIGERIA	GHANA	KENYA	RWANDA
Permitting and licensing structure for collectors and recyclers				
	✔	✔		✔
Clear definition of "producer" (for EPR-based legislations)				
✔	✔		(✔)	✔
System control (e.g., reporting obligations, "free riders", penalties)				
✔	✔		(✔)	✔
Definition of compliance requirements				
✔	✔		(✔)	✔
Informal sector explicitly mentioned?				
✔	✔	✔		
Chemicals of concern/hazardous fractions explicitly mentioned?				
	✔	✔	(✔)	✔
PRO status requirement				
Non-profit	No specific requirement	No specific requirement	Non-profit (draft)	No specific requirement
Existing PROs				
Lightcycle SA; E-Waste Recycling Authority (ERA); South African Waste Electrical and Electronic Enterprise Development Association (SAWEEDA); Southern African E-waste Alliance (SAEWA)	E-waste Producer Responsibility Organization of Nigeria (EPRON)			
SELECTED System actors				
Nearly 80 registered companies including refurbishers, dismantlers, collectors, manufacturers, vendors and distributors (E-waste Association of South Africa (EWASA))	Three registered recyclers	Electronic Waste Round Table Association (EWROTA); Caritas Ghana E-waste Campaign	Seven centres licensed for hazardous waste collection; WEEE Centre	Enviroserve Rwanda Green Park operating a dismantling plant potentially covering 100% of the e-waste generated in Rwanda
Strengths				
Industry-driven regulation with flexibility in establishing an EPR; quantitative targets for collection and recycling; sanctions for non-compliance (prison term and fines)	Strong initiative and support from the government to implement and enforce the EPR policy; defines obligations for most actors in the value chain; prohibits suboptimal treatment of e-waste; support from the private sector is also significant, code of ethics for EPR implementation	Legislation stipulates creation of a national fund; obligations for product take-back	Comprehensive definitions of key terms; re-design, reuse and waste prevention are part of producer obligations; PROs are obliged to raise awareness and finance cross-sectoral communication; restrictions on use of hazardous substances by the producers; producer fees are related to product sustainability*	Provides technical requirements for collection, transportation, dismantling, refurbishing and recycling; defined hazardous fraction obligations for producers and recyclers; defined consumer responsibilities

SOUTH AFRICA	NIGERIA	GHANA	KENYA	RWANDA
Weaknesses				
Key terms (recovery, collection, recycling, etc.) are not defined; no specific measures to raise awareness, prevent waste generation or improve product design; hazardous fractions are not explicitly addressed	Limited focus on product design; no specific measures to integrate the informal sector clearly defined	No clearly defined roles for different actors; no specific measures for organization, licensing, management and control of the system; fixed fees to be paid by the producers; fixed allocation of funds, including 30% to the authorities with no clear description of their role	Quantitative targets are to be set by the PROs; no EEE definition; no specific measures to integrate the informal sector	Legal framework with no operational regulations; no clear guidance on establishing an EPR; no quantitative targets; lack of focus on waste prevention and eco-design; no specific measures to integrate informal sector

1 Act No. 59, 2008: National Environmental Management: Waste Act. Government gazette, Vol. 525, No. 32000

2 Government Notice No. 1184, 2020: Regulations regarding extended producer responsibility. Government gazette, Vol. 665, No. 43879

3 Government Notice No. 1184, 2021: Amendment of regulations and notices regarding extended producer responsibility. Government gazette, Vol. 667, No. 44078

4 Government Notice No. 1185, 2020: Extended producer responsibility scheme for the electrical & electronic equipment sector. Government gazette, Vol. 665, No. 43880

5 Government Notice No. 1186, 2020: Extended producer responsibility scheme for the lighting sector. Government gazette, Vol. 665, No. 43881

6 Government Notice No. 137, 2011: National Environmental (Electrical/Electronic Sector) Regulations. Federal Republic of Nigeria Official Gazette, Vol. 98, No. 50

7 National Environmental Standards and Regulations Enforcement Agency (NESREA). Guidance Document for the Implementation of the Extended Producer Responsibility (EPR) Programme for the Electrical/Electronics Sector in Line with Circular Economy, August 2020, Abuja, Nigeria

8 Act No. 917, 2016: Hazardous and Electronic Waste Control and Management Act. Republic of Ghana

9 Legislative Instrument (LI) No. 2250: Hazardous and Electronic Waste Control and Management Regulations. Republic of Ghana

10 Technical Guidelines on Environmentally Sound E-waste Management for Collectors, Collection Centres, Transporters, Treatment Facilities and Final Disposal in Ghana. Environmental Protection Agency of Ghana and Sustainable Recycling Industries, 2018

11 The Environmental Management and Co-ordination (Extended Producer Responsibility) Regulations (draft). Ministry of Environment and Forestry of Kenya, 2020

12 Regulation No. 002 of 26/4/2018 Governing E-waste Management in Rwanda. Official Gazette no. 31 of 30/07/2018

* Recyclability, presence of hazardous substances, product environmental footprint, existence of markets for secondary materials, etc;
(✔) Indicates draft legislation.

As illustrated in Table 3.3 using the example of five selected countries, the state of EPR-related legislation in Africa differs significantly, from basic pieces of legislation in Ghana, stipulating the take-back responsibility of producers and creating national fund, to relatively advanced EPR legislation in Kenya, focusing, among others, on re-design, reuse and prevention, CoC, and adjusting producer fees based on product sustainability. However, despite the informal sector's particularly important role in the current management of e-waste, it is barely mentioned in the legislation and specific measures to integrate the informal sector into newly proposed systems are very limited. For example, Ghana's EPA technical guidelines suggest a five-tier approach, which sets a framework for informal and formal sector partnerships for sustainable e-waste management (Hinchliffe *et al.*, 2020). Furthermore, the issue of CoC and fate of hazardous fraction resulting from e-waste recycling are largely overlooked. Finally, most regulations focus on the EoL stage of the electronics value chain, paying limited attention and not providing for any specific measures on product eco-design and waste prevention.

Despite progress made on the legislative bases, even the most comprehensive and advanced pieces of legislation have little effect without proper implementation and enforcement. Commercial, organizational, historical and cultural aspects influence the way EPR schemes are designed and implemented, hence, the need for flexibility and the fact that a direct comparison between countries should be made with caution (EC, 2014b). However, in some countries, the legislative basis for EPR has existed for several years without effective implementation, enforcement and establishment of functioning PROs. Core issues associated with the lack of "take-off" funds to establish collection and treatment capacity, corruption, and unfair competition with the informal sector hamper the implementation of EPR schemes and effective e-waste management in most countries in Africa.

3.4 Recommendations along the electronics value chain for Africa

The ideal outcomes of implementing a circular economy in the electronics sector in Africa can include:

Effective policy, appropriate business models, and sustainable product design deliver products that are non-toxic, last longer, and are easy to reuse, repair and recycle in Africa. Responsible producers and businesses manage EoL electronic products safely, recover resources efficiently and reduce pollution. Sustainable markets for recovered materials generate added value in Africa, reduce dependence on natural resources, and create decent, inclusive work and economic growth.

To ensure that the electronics sector in Africa is moving towards a circular economy, the gaps and limitations of the existing system should be addressed. The following sections provide a brief overview of specific recommendations to contribute to improving the priority areas and reflecting on the current state of the electronics value chain in the region (Section 3). Recommendations focus on the individual life cycle stages of the electronics value chain and aspects cross cutting the value chain, such as policy, knowledge and finance. Building on these recommendations, a list of actions for achieving a circular economy is proposed in Section 4, providing concrete actions to address the priority areas and identifying the key stakeholder groups driving the actions.

3.4.1 Design

Appropriate design interventions can improve the environmental impacts of products throughout their lifespans. Although most electronic products are neither designed nor produced in Africa, regulators in Africa can promote sustainability in design by establishing requirements for imported products and by using appropriate financial instruments, such as taxation and subsidies. Such actions should be carried out in cooperation with large producers and importers of equipment, securing their engagement and commitment. A set of common requirements for the African market should be considered, while leveraging the size of the market, rather than creating fragmented policies that pose significant compliance obstacles for producers and importers. In addition, any future expansion of regional production (see Section 3.4.2) should be accommodated through an appropriate focus on design requirements, not only for imported products (currently accounting for the vast majority of consumption), but also for products produced in the region. Authorities should incentivize the use of and set targets for recycled material in electronic products, while designers and producers should strive for more durable products that can serve for longer periods and can be repaired easily and cost-effectively and should also consider product recyclability in the design stage. Modular design solutions, where products and components are designed for easy disassembly would allow cost-effective product repair and better recycling, even by using simple tools and processes commonly employed in many African countries. Material complexity should also be reduced, for example, by reducing the number of materials used, simplifying material formulations and by using screws and clips instead of soldering and glue to attach product components. International standards also provide assessment methods to improve the circularity of electronics at the product design stage. For example, International Telecommunication Union (ITU) Recommendation ITU-T L.1023 provides an assessment method for scoring the circularity of ICT goods, which helps product designers determine the most relevant circular criteria to incorporate into their product design, namely, reduction of material use, reuse, recycling and recovery of products, product parts, components and materials. Finally, electronics should still be affordable, provide basic services to the entire population, reduce inequality and promote development.

The use of CoC in products should be significantly reduced and eliminated in the medium to long term. This requires the prioritization of CoC that are most relevant to the African region, followed by coordinated action by regulators and businesses, through an appropriate chemical ban, and through labelling and substitution legislation, such as the RoHS regulations. Electronics placed on the African market should comply with restrictions on the use of CoC, while transparency in the material chain, for example by including details of all the materials and chemicals used in a product, should be further improved. Since a large part of electronics design and manufacturing occurs elsewhere, the exchange of information and collaboration should be fostered by national governments, product importers, producers and designers.

Finally, national authorities should encourage the energy efficiency of products on the African market by utilizing taxes and subsidies, while customers must be informed about the energy efficiency of the products through mandatory energy labelling and information campaigns. Examples of energy efficiency projects do exist in the region, which, combined with measures, are already setting positive trends, for example, refrigeration appliances in Ghana (Ghana Energy Commission, 2019).

3.4.2 Production

There is a need to establish a basis for the production of electronics in Africa and, accordingly, a number of African countries are working towards establishing and expanding domestic electronics production in the region (see Section

3.1.2). It is vital to make sure that the newly established capacities adopt high standards of production, ensuring that carbon emissions, pollution, and the environmental and social impacts of production are minimized and strictly controlled. National authorities should set appropriate emission limits, monitor industrial emissions and develop emission reduction strategies, while producers should follow industry guidelines, report non-financial data and set targets for emission and impact reduction. Furthermore, the expansion of regional production could also entail more control over product design and specifications, providing an opportunity for improved consideration of regional specificities and requirements, and the integration of circularity into the product development stage.

In accordance with life cycle thinking, the sustainability and circularity of raw materials procured in Africa should be improved. National authorities should define and set sustainability criteria for mining activities, including informal mining integration, and monitor compliance. International brands should perform appropriate due diligence with regard to their supply chains in Africa, eliminating suboptimal informal mining and recycling and ensuring appropriate labour and living standards for people employed within the value chain. The reuse of components in repairing, refurbishing and remanufacturing, already commonly practised in Africa, should be promoted and incentivized. The availability of regionally-sourced secondary materials from the e-waste generated in Africa should be considered explicitly in production, allowing for enhanced circularity and potentially closing some of the material loops. Investments in the sector should be linked to resource and circularity metrics, incorporating non-financial factors into financial decision-making. Bridging primary (i.e., mining) and secondary (i.e., recycling) raw material sectors should be done with care to reduce potential resistance and to promote fair competition.

3.4.3 Consumption (use and reuse)

Decoupling demographic and economic development from the rapid increase in electronics consumption is a necessity, and would make time for the development of the necessary policy frameworks, mechanisms, such as EPR and infrastructure to support such an increase in production and e-waste handling.

National authorities should play a key role in making electronics consumption more sustainable, by creating incentives to change behaviour, using green public procurement, providing legal frameworks for novel business models optimizing resource use and minimizing waste generation, including product-as-a-service and product sharing, and repairability indexes. Government actions should be supported by product designers and manufacturers, in order to create better suited products that are, for example, more durable and easier to repair, and to delay the obsolescence of electronics by providing repair guidelines, spare parts and software support for a product's lifespan, for example.

The existence of a large market for second-hand equipment and a network of — often informal —repair and refurbishing activities in Africa allows for the sector's future growth and formalization. Considering the potential economic, environmental and social benefits, the formalization of electronics repair and refurbishing activities should play a key role in creating formal employment in the sector, extending product lifespan and reducing dependence on new, imported products. Government incentives, such as tax breaks for repair enterprises and legislating on the consumer's right to repair, by setting minimum warranty requirements and using a repairability index, for example, should facilitate the future expansion of the sector.

Finally, African consumers, guided by NGOs and incentivized by governments, should have the necessary knowledge to make more sustainable choices. Awareness campaigns, appropriate product labelling and dedicated information platforms should improve people's understanding of the impacts the products they purchase have throughout their lifespans. Consumers can play an important role in the electronics value chain by demanding safer, easier to repair, recyclable products.

3.4.4 E-waste collection

While there are a number of formal e-waste collection initiatives in Africa, they are in their infancy, and most resulting electronic waste is collected by the informal sector. The importance of separating e-waste from other wastes at source should be clearly communicated through guidelines, targeted information campaigns and training for households, public institutions and businesses, and the necessary infrastructure for the formal, separate collection of e-waste, using dedicated bins, drop-off and centralized collection points, for example, established and expanded. Authorities should ensure that collection services are delivered, starting with priority areas, such as high-density residential areas and electronics markets. Responsibility for e-waste collection should be delegated through EPR regulations and should include a variety of reverse logistics channels, including informal collectors, electronics distribution, sales and service networks, and take-back and buy-back schemes. National authorities and municipalities are encouraged to use international standards to guide the implementation of their EPR systems. Standards, such as those developed by the ITU Telecommunication Standardization (ITU-T), can help to define the implementation model of different EPR systems, the responsibilities of key stakeholders, and identify prerequisites and supplementary measures for EPR. Considering the high collection rates achieved by the informal sector, simply prohibiting its activities or competing with the informal sector is not an effective solution (Chi *et al.*, 2011). The success and effectiveness of formal e-waste collection depends on collaboration with and integration of informal e-waste collection channels (Hinchliffe *et al.*, 2020).

A key element of ensuring human health and environmental protection from the potential impacts of e-waste is through the collection of e-waste fractions containing CoC (Hg, certain FRs, certain phthalates, etc.). These fractions provide little income to recyclers and are therefore often not collected or appropriately treated, releasing CoC into the environment. National authorities should explicitly stipulate the obligation of e-waste collectors to collect all e-waste, irrespective of its value. This should be supported by appropriate guidelines and training for the identification, separation and collection of e-waste fractions containing CoC, developed in collaboration between producers, NGOs and industry. In the initial stage of implementation, informal collectors could be engaged in the incentivized collection of problematic e-waste fractions, by being paid a set fee for bringing in hazardous materials, for example, building on the positive experiences of existing pilot projects in the region (Manhart *et al.*, 2020).

3.4.5 E-waste recycling

Most e-waste recycling in Africa is performed on an informal basis using rudimentary tools and processes. Such recycling is often focused on bulk metals (copper, iron, aluminium, etc.), while other components and materials are either exported after disassembly or lost. Ensuring that more materials from e-waste are recycled is paramount and recycling technology available in Africa should therefore be improved and the available capacities and infrastructure for recycling expanded. To ensure that adequate amounts of e-waste are collected, authorities should eliminate e-waste dumping and open burning, ensuring that such activities are monitored and potential restrictions enforced. A functioning financial mechanism for the recovery of materials with low market value or that are difficult to recover should be established, integrating the informal sector into the formal electronics value chain. Standards can be leveraged to identify the need for safe recycling in the informal sector, formalize its working practices, while recommending measures that may help the sector's activities become environmentally friendly, protect workers in the sector and potentially transform the informal sector into a formal sector.

Materials recycled from e-waste currently have a limited market in Africa. Expanding the markets for recycled materials, including by creating a marketplace and developing innovative applications or material formulations used in production, is necessary to increase the amounts and quality of materials recycled from e-waste in the region.

Recycled material quality is related to the presence of CoC, for example, in plastic recycled from e-waste. Separating additive-rich and CoC-contaminated fraction of plastic before recycling is paramount to recyclate quality and can be achieved using low-tech, inexpensive and highly effective methods, including manual sorting based on marking on plastic, or water-based density separation (Haarman *et al.*, 2020). The resulting contaminated fraction should be treated appropriately. Since existing capacities for hazardous waste treatment in Africa are limited, a centralized, regional facility should be considered, establishing partnerships between neighbouring countries, and procedures for the transboundary movement and environmentally sound management of materials should be developed and aligned with existing regulations and conventions.

3.4.6 Enabling conditions

3.4.6.1 Knowledge, collaboration and innovation

Detailed knowledge about the electronic product value chain in Africa is limited. There is a need for adequate reporting mechanisms, setting and enforcing reporting requirements and developing capacity for data collection and processing. National inventories for trade in UEEE, product repair and reuse, e-waste generation, collection and recycling should be linked with due diligence requirements for producers, importers and exporters. Reported data should be used for statistical analysis on national and regional levels, illustrating the status of consumption, (i.e., reflecting on prevention targets), reuse and recycling, as well as demonstrating the progress towards e-waste diversion from dumping and landfill, and informal sector integration. Information from national registries should be used to guide sustainable consumer choices and empower behavioural changes to embrace more circular options. Regional certifications and standards should be developed to cover the entire electronics value chain in Africa. Legal frameworks based on robust data should be expected to be more tailored and better regulated.

In addition to appropriate financial incentives, a key element of informal sector integration is the development of education and training programs, focused particularly on MSMEs and carried out by involving stakeholders from the government, industry and academia in PPPs. Priority groups with a need for formal education and training are informal miners, collectors, dismantlers and recyclers of e-waste in Africa.

Rudimentary and suboptimal processes involved in mineral mining or e-waste treatment in Africa are associated with emissions (including CoC), resulting in negative human health and environmental impacts. Reliable and quantitative data on such impacts should be generated and used to further raise awareness among workers and the affected population. In parallel, the processes creating those impacts should be eliminated, while technology solutions for mining and the refining of minerals for electronics, or e-waste dismantling and recycling should be significantly improved. It is paramount that capacity for formal e-waste collection and treatment is established and expanded in all African countries.

In addition to being a national issue of concern in many African countries, achieving progress towards a circular economy requires regional and global efforts. The Africa region can better foster collaboration with international organizations dedicated to expanding the region's capacity for sustainable e-waste management and leverage relevant standards to guide the transition towards circular electronics. Integrating the topic further into regional forums and advocating African interests throughout the global electronics value chain would allow strategic decision-making, transparency and increase capacity for learning and innovation in the sector. Global brands play an important role in the process, working jointly with their value chain actors and suppliers in Africa. Innovation and entrepreneurship play a central role in transforming the electronics sector in Africa. This spans from innovative product designs and solutions, digital innovation, to the development of novel processes for mining and e-waste treatment that take regional specificities into consideration.

Box 3. Internet-based solutions connecting key players within the electronics value chain

Effective communication between key stakeholders within the electronics value chain is often lacking. For example, a person wanting to sell a used electronic device, repair a broken appliance or appropriately dispose of e-waste may have difficulty in doing so due to a lack of functional formal infrastructure in the region. However, once again, electronics themselves can be part of the solution to the issue of electronics circularity. Internet-based solutions have been developed and tested in various countries in Africa, offering necessary services and supporting the creation of a more transparent and effective system for a circular economy in the electronics sector.

E-commerce platforms and marketplaces offer an outlet for electronic products and a growing number of platforms support or even focus on second-hand products, including electronics. Large amounts of electronics are sold in this way, with national, rather than international, platforms dominating the markets in a number of African countries, including Nigeria, Kenya and South Africa (Kaplan, 2018).

Internet-based solutions focused on e-waste collection are also growing in popularity. Platforms under development offer users the opportunity to take a photo of a device they do not need any more with a short description and to add it to a platform where potential repairers, waste collectors, recyclers or even producers (through their product distribution network) can offer cash or a discount on a new product in return for collecting the e-waste. An application being tested in Rwanda has helped the collection and formal recycling of more than 400 tonnes of e-waste, while in Egypt, an app connecting e-waste producers and formal collectors is being developed in collaboration with the national authorities and intergovernmental organizations (Kidmose, 2019; MCIT, 2020). In South Africa, waste producers are matched with private owners of trucks, allowing for the efficient, cost-effecting and transparent collection and transportation of waste (including e-waste) on demand (Liedtke, 2019). The use of such platforms and the services they offer are further facilitated by mobile payment platforms (e.g., M-Pesa in Kenya, Tanzania, Ghana, Egypt, South Africa), which make transactions easier and help informal sector integration (Manhart et al., 2020).

Due to a lack of functional formal infrastructure in Africa, internet-based platforms and services have the potential to improve electronics circularity: more electronic products are formally collected, repaired, reused and recycled. This can be achieved in a transparent way, raising awareness among the population and building lasting trust-based relationships. However, several challenges hamper regional development and the more rapid adoption of internet-based solutions. While internet coverage in Africa is growing, it remains the region with the lowest internet usage rates, below 30% of the population (ITU, 2019). Furthermore, the lack of functional controlling mechanisms may allow fraud, which aggravates potential users' trust. Finally, and like other formal activities in the e-waste sector, internet-based services must often compete on unfair basis with the dominant, informal network of e-waste collectors and recyclers.

The challenge	Lack of communication and coordination of activities within the electronics sector on the continent is a preventive aspect, limiting innovation and integration of circularity into the value chain
The solution	Internet-based platforms can offer a means of efficient communication among key stakeholders and enforce circularity behaviour in the environment that lacks functional, formal infrastructure
The benefits	1. More electronics reuse and a more organized second-hand market 2. Traceable collection and treatment of e-waste 3. Transparency and higher trust among value chain players
What makes it circular?	Provides enabling conditions that can support material reuse, better e-waste collection, formal recycling, tracing material treatment and destinations for recycled materials
What are the main barriers?	1. Low internet coverage 2. Awareness and competition with informal sector 3. Lack of trust, fraud and control 4. Financial sustainability
Main lifecycle stages	• Consumption (service, repair and reuse) • EoL (collection)
SDGs	12 RESPONSIBLE CONSUMPTION AND PRODUCTION; 7 AFFORDABLE AND CLEAN ENERGY

3.4.6.2 Policy, implementation and financing

The transition to a more circular value chain requires comprehensive policy instruments directly and indirectly addressing the entire life cycle of electronics in Africa. This includes policies, regulations and standards on product design, labelling and certification, use of CoC, product warranty and the right for repair. In addition, dedicated resources for enforcement, monitoring and capacity-building are necessary to make policy operational and its implementation effective. Furthermore, immediate actions are required with respect to critical aspects, such as e-waste collection, environmentally sound management and e-waste fractions containing (and releasing) CoC.

The digital product passport is a new policy instrument offering an effective way to track and trace a product, including information on its origin, composition, and even EoL options. Therefore, the digital product passport can be a significant tool to boost the implementation of circular principles in electronic products (ITU, 2021). Currently, the requirements for such passport are being studied and relevant standards are expected to be developed in the future. The concept has already been gaining significant traction at the European level and could also be adapted to the African region.

While some countries have national regulations at least partially addressing the electronic waste issue, in the majority of countries, such regulations are either not in place or are not implemented or enforced. Tackling the e-waste issue is an important milestone towards implementing the circular economy for the sector in Africa. However, more comprehensive policies and regulations addressing the complete life cycle of electronics, namely, on EPR, at the national and regional levels are needed. Considering the potential for cooperation and coordinated actions in the region, a level of transparency and harmonization of regional legislation and national EPR schemes could improve cost-effectiveness and maximize positive results. This should be carried out by integrating existing regional initiatives, such as the regional e-waste strategy for the East African countries (EACO, 2017).

When developing new regulations, designing EPR schemes or establishing PROs, the following aspects appear to be critical in the region and should be explicitly considered:

- Clear definition of objectives and key terms (circular economy, producers, recycling, etc.)
- Clear definition of responsibilities and roles of all actors (including national and local authorities) within the electronics value chain
- Waste management hierarchy
- Environmental consideration of product lifecycle
- Financial transparency and incentives for actors to improve the system
- Integration of the existing informal sector into the formal EPR-based system

Currently in Africa, the informal sector is the driving force behind the key stages of the electronics value chain. A large number of people involved primarily in e-waste management account for vulnerable segments of the population. Establishing EPR schemes for electronics and formalizing the sector should be carried out in a gradual and inclusive way, for example, by starting with informal-formal sector collaboration partnerships, through which affected people are consulted, incentivized, educated and trained. Necessary measures should be planned to identify and utilize key drivers and incentives for the informal sector, while securing acceptance and minimizing the potential resistance to changes. Within EPR, concrete plans should be devised and targets set for partnerships with and integration of the informal sector, specifically supporting the participation of women.

While adhering to existing international conventions and national regulations, restricting the movement of used electronics and e-waste should be carried out with care, in order to avoid illegal dumping of e-waste and its related negative impacts, while supporting development, fostering regional collaborations, establishing centralized production and waste treatment facilities and securing the necessary supply to achieve an economy of scale. Dedicated capacity to identify and prevent illegal trade should be established and procedures for the transboundary movement of used electronics and e-waste should be improved and simplified, by differentiating between new and used equipment trade, digitalizing processes governed by the Basel Convention and pre-approving e-waste exporters and importers, for example. This will require an international effort from both importing and exporting countries.

The global financial sector sees electronics as a key sector to finance circularity (UNEPFI, 2020) and can provide the necessary capital to foster innovation, and establish EPR organizations and necessary e-waste collection and recycling capacities. This requires coordinated regional government action, through which strategic investment plans should be developed and established. Furthermore, governments, together with financial institutions, should play a key role in de-risking and making the sector viable for investment. In particular, the important role of MSMEs in the circular transition for electronics in the region and their financing needs should be understood by the financial sector. To support development and financial sustainability of the EPR system in importing countries, countries with EPR systems exporting UEEE to Africa should have a degree of shared responsibility.

Finally, the issue of corruption remains an important factor that is detrimental to the broader economic development of the region, which is assessed to be on the rise and with many African governments failing to do enough to combat it (Pring and Vrushi, 2019). Basic mechanisms needed to reduce the spread of corruption include convenient and safe reporting of corruption, guarantee of an action, free space for NGOs to operate and making governments accountable.

4. PRIORITY ACTIONS TOWARDS A CIRCULAR ECONOMY FOR ELECTRONICS IN AFRICA

The priority actions listed in this section aim to provide concrete and actionable steps for key stakeholders to implement the recommendations outlined in Section 3.4, to ultimately transform the electronics value chain in the region and make electronics an exemplary case of a circular economy in Africa. Achieving greater circularity for electronics means reducing the reliance on virgin natural resources, increasing electronic product lifespan, improving product reuse, repair and refurbishment, reducing e-waste generation, developing e-waste collection and recycling infrastructure, minimizing the release of CoC, improving the recovery of materials, increasing recycled content in new products and creating decent jobs in Africa. Novel business models, such as product-as-a-service, access over ownership, product sharing platforms, play a crucial role in dematerializing the electronics product supply and integrating circularity into the value chain.

These priority actions address the nine main circularity strategies (9Rs), i.e., reduce by design, refuse, reuse, reduce, repair, refurbish, remanufacture, repurpose and recycle. Time wise, the actions are separated into short term (5 to 10 years) and medium to long term (over 10 years), depending on how much time is potentially needed to implement an action. The vision summarizing the anticipated effects of the proposed actions, is outlined as follows:

- **Short term.** The relevant legislation is harmonized in accordance with the circular economy approach for electronics and provides opportunities for international links (e.g., collection of e-waste in Africa counting against collection targets elsewhere). Due diligence of the electronics supply chains in Africa is mandatory. Pilot activities are developed and documented, supporting informed decisions and local capacity development. Appropriate minimum product design and quality standards are developed, enforced and controlled. An established knowledge base on CoC in electronics leads to the regulation of CoC use and the appropriate management of relevant e-waste in Africa. Minimum product warranty periods are set. The electronics repair sector is strengthened and the right to product repair is legislated. Instruments to increase the use of recycled materials and reuse of components is in place. The capacity for relevant data reporting and communication is established. Key actors in the value chain, such as MSMEs, are educated and trained. Measures to prolong product lifespan are in place. The regional marketplace is used for recycled materials from e-waste. The feasibility for regional e-waste management facilities is assessed. Commitments for regional and national investments in the sector are made, integrating circularity into assessment criteria and simplifying procedures. Capacity-building on the circular economy for electronics is integrated into the value chain, regional forums, platforms, and society through education and training. Links between rudimentary practices in the sector and negative impacts on human health and the environment have been quantitively established and relevant stakeholders informed. Incentives for better e-waste collection are provided, also leveraging existing informal networks. While e-waste dumping and open burning is very limited, landfill is being gradually phased out to optimize material recovery.
- **Medium to long term.** An EPR framework for electronics is developed and enforced. Appropriate standards, labels and certifications systems are commonly used within the electronics value chain in Africa. Sustainable electronics are part of public procurement practices. The sustainability-driven movement of e-waste is efficient and transboundary movements are controlled. Work within the electronics value chain is documented and formalized, maintaining and generating new, decent jobs on the continent. Innovation in the sector is supported by a continuous peer learning process. Key drivers of circular consumption and sustainable behaviour in the region are being studied and integrated into decision-making. Innovative product and service designs are being piloted and scaled up. Products on the market contain no CoCs, and novel solutions are used for safe recycling of CoC-containing e-waste. Most functioning components from EoL products are reused. Digital solutions are commonly used for product reuse, e-waste collection, product and material tracing. All e-waste is collected and documented, while most materials from EoL products are sustainably recycled. Strategic investments, supported by the government, are made available for infrastructure and capacity expansion, while access to financing is made easy for MSMEs, researchers, innovators and entrepreneurs. Extended due diligence of the value chain is carried out by brand owners and manufacturers, while consumer and stakeholder behaviours are guided using reliable sustainability data and information.

These priority actions for a circular economy for electronics in Africa build on the structure of the existing value chain, socio-economic background and practices, current laws and regulations, as well as state of their enforcement and progress monitoring. They take a systematic approach to address the main issues identified in this report, which if solved, would allow for a transformation towards a circular economy for electronics in the region. This takes into account following key elements for a circular economy transition in Africa:

- **Stakeholder engagement.** A paradigm shift in the electronics value chain requires a significant level of harmonized engagement from most stakeholders: the private sector, including product designers, producers, collectors and recyclers (formal and informal), electronics consumers, municipalities, local and national authorities, regional and intergovernmental organizations, industrial associations and social society groups. International stakeholders play an important role here, considering most electronics (new and used products, illegal e-waste imports) are produced elsewhere and imported in the region.
- **Life cycle thinking.** The environmental, social and economic impacts of electronic products should be considered over their entire life cycle, starting from the extraction of natural raw materials, product design and production, packaging and distribution, product use and maintenance and finally EoL product disposal, in adherence to the decision hierarchy (i.e., reduce, reuse and recycle).
- **Chemicals of concern (CoC).** The exposure to and damage from CoC should be eliminated. Their use should be minimized and adequately labelled in products and the components they are used in, allowing for better disassembling, separation and ultimately recycling or appropriate disposal.

Table 4.2 provides an overview of the priority actions proposed for advancing a circular economy for electronics in Africa. It is split into five action domains: (1) policy and governance; (2) knowledge creation; (3) innovation, technology and infrastructure; (4) financing; and, (5) capacity development, awareness-raising and advocacy. The actions are ordered according to the principal circularity strategy they address, starting from actions with significant effects across the circularity strategies (i.e., 9Rs). While it is clear that almost none of the actions can be achieved by a single group of stakeholders and coordinated actions are required, a key, driving, stakeholder group has been identified for each of the actions. The role of the key stakeholders is to drive the change, identifying relevant stakeholders to partner with and factors driving their commitment and engagement in supporting the action. Furthermore, actions are assigned a geographical scale (global, regional, national, or local) according to the level of decision-making necessary and implementation scope for each of the actions. Finally, while the need for actions is acute and work on their implementation should commence immediately, the duration for action implementation may differ, either due to the complexity of an action or the potential interdependences of actions. Hence, a time frame is associated with each action, with “short” implying anticipated implementation within the next 5 to 10 years, while “medium to long” implies that a longer period of time (over 10 years) is potentially necessary.

While the Table provides a list of actions to be driven by respective stakeholders, the monitoring of action implementation and their effectiveness is an important aspect of the circular economy transition in the region. Such monitoring should be done in coherence with the respective actions and carried out by the appropriate stakeholders, potentially different to the driving stakeholders associated with the specific actions in Table 4.2.

Table 4.2. Priority actions towards a circular economy for electronics in Africa

ACTION DOMAIN	Action description	Scale	Principal circularity strategy	Time frame	Key (driving) stakeholders
1. POLICY AND GOVERNANCE					
	Set mandatory due diligence and supply chain transparency requirements, explicitly focusing on labour rights and working conditions in mining and e-waste treatment in the electronics supply chain in Africa	Global, regional	9Rs	Short	Policymakers and regulators
	Harmonize product and chemical regulations, waste and environmental legislation, EPR framework, and trade regulations in accordance with the regional circular economy approach for electronics in Africa	Regional	9Rs	Medium to long	
	Using eco-design principles, set minimum design requirements for domestic production and imports to allow cost-effective product disassembly for repair, remanufacturing, component reuse and material recycling	Regional, National	Reduce by design	Short	
	Develop national or adapt existing international standards, labels and certification systems for mining, product design, energy efficiency, imports of used EEE, e-waste collection, treatment and quality of secondary raw materials	National	9Rs	Medium to long	
	Develop and enforce EPR legislation for electronics, with an implementation strategy, targets and operational guidelines. Legislate a shared degree of responsibility in countries exporting to Africa	National	9Rs	Medium to long	
	Strengthen customs control for used electronics and illegal e-waste imports into Africa. Facilitate exports of waste electronic fractions from African countries for recovery and disposal when there is no local solution	National	9Rs	Medium to long	
	Devise a strategy for the reduction and substitution of CoC used in electronics on the African market, i.e., ban priority CoC, require labelling and marking of CoC-containing materials and components (RoHS-like legislation)	National	Reduce by design	Short	
	Set minimum and extend warranty periods for new, used, repaired and refurbished electronics sold on the African market. Legislate the consumer right to access product repair	National	Repair, refurbish, remanufacture	Short	
	Create policy instruments to increase uptake of recycled materials and component reuse. Set targets for the recycled content of electronics produced or imported into Africa	National	Reuse, repair, remanufacturing, recycle	Short	
	Set ambitious national targets and monitor progress for UEEE and illegal e-waste imports, e-waste generation and collection, regulated and un-regulated (informal) recycling sectors	National	Reduce, recycle	Short	
	Ban e-waste dumping and open burning (short term). Gradually phase out landfill for e-waste and derived materials (long term). Introduce appropriate fines for non-compliance	National	Recycle	Short to long	
	Enable informal sector integration and entrepreneurship by (a) simplifying procedures for establishing cooperatives and MSMEs; (b) providing incentives for formal enterprises; (c) significantly improving working conditions in the sector	National, local	Reduce by design, repair, recycle	Medium to long	
	Develop pilot activities, start-ups, innovative circular products, services and business solutions	National, local	9Rs	Short	
	Develop appropriate criteria and procedures for sustainable procurement of electronics	National, local	9Rs	Medium to long	

2. KNOWLEDGE CREATION

Facilitate peer learning and innovation by sharing examples of circular business models, novel technical solutions, and case studies between African countries and international stakeholders	Global, regional	9Rs	Medium to long	Policymakers and regulators
Establish systems for comprehensive data reporting and sharing on product imports (including used EEE), reuse, repair, and e-waste generated, collected and recycled in Africa	National	9Rs	Short	
Create a knowledge base on use and emissions of CoC from electronics in Africa, prioritize key CoC for the region and facilitate information exchange on substitute availability and applicability	National	Reduce by design	Short	IGOs, CSO, researchers and academic institutes
Create region-specific guidelines for the identification, separation, collection and treatment of CoC fractions of e-waste	National	Reduce, recycle	Short	
Provide training for MSMEs (e-waste collectors, dismantlers and recyclers, etc.) and support cooperation with and integration of informal sector	National, local	Reduce by design, repair and recycle	Short	
Use target groups and surveys to study urban consumer behaviour with respect to electronics reuse, repair, e-waste disposal and uptake of novel business models and prioritize the key drivers of circular consumption in African cities	Local	Reduce by design, refuse, reuse, repair	Medium to long	
Carry out biomonitoring, environmental impact and risk assessment studies quantitatively linking specific practices in electronics-related mineral extraction, refining and e-waste treatment to health and environment impacts in Africa	Local	Reduce, recycle	Short	

3. INNOVATION, TECHNOLOGY AND INFRASTRUCTURE

Develop innovative circular product, service and business solutions. Pilot and scale up innovative and promising product and service designs applicable and effective in the African context	Global, national	9Rs	Medium to long	Raw material producers and manufacturers
Increase product lifespan and delay obsolescence of electronics by making spare parts and repair guidelines available, and providing extended software support	Local	Reuse, repair, refurbish, remanufacture	Short	
Assess feasibility for shared, regional infrastructure projects for e-waste dismantling, recycling and hazardous waste treatment involving several African countries	Regional	Recycle	Medium to long	Innovators and recyclers
Create a regional marketplace for sharing trade information of recycled materials from e-waste in Africa	Regional, national	Recycle	Short	
Improve e-waste product dismantling processes to separate e-waste components to maximize reuse	National	Repair, refurbish, remanufacture	Medium to long	
Develop safer, more efficient and cost-effective processes and applications for the recovery of materials that are difficult to recover (e.g., rare earth metals) and recycle (e.g., plastics) from e-waste in Africa	National	Recycle	Medium to long	
Conduct feasibility studies and develop pilots for national e-waste collection, dismantling and recycling facilities and infrastructure	National, local	Recycle	Short	
Foster cross-cutting digital innovation (e.g., internet-based solutions and apps) for effective product reuse, reliable e-waste collection and material tracing	Local	Reuse, repair, recycle	Medium to long	
Create innovative, CoC-free product designs. Develop novel solutions for the safe recycling of CoC-containing materials	Local	Reduce by design, recycle	Medium to long	
Set up diverse collection channels and implement effective e-waste take-back and buy-back schemes for individual consumers, businesses and the public sector. Engage with informal e-waste collectors	National, local	Recycle	Medium to long	Brands and retailers

4. FINANCING

Develop strategic circular economy investment plans for circular design, production, use, value recovery and enabling models, and integrate circularity criteria into project funding screening	Regional, national	9Rs	Medium to long	Policymakers and regulators
Provide government-backed guarantees, including PPPs, for investments in priority areas, such as the expansion of a formal e-waste collection network, and the improvement of sorting and recycling technology in Africa	National	Recycle	Medium to long	
Formalize the dedicated regional and national economic support programs and commitments for a circular economy for electronics in Africa. Set investment goals and monitor progress	Regional, national	9Rs	Short	Financial institutions (e.g., MDB)
Provide initial investment capital to establish EPR organizations for electronics in African countries	National	9Rs	Short	
Develop a dedicated framework to lower investment risk and to offer favourable credit pricing to accommodate novel business models, e.g., product-as-a-service, product sharing and leasing in the electronics sector in Africa	National	Reduce by design	Short	
Provide venture capital for research and early-stage innovation in novel business models for electronics, technology development for e-waste treatment, and product and formulation development for e-waste reuse and recycling	National	Reduce by design, reuse, remanufacture, recycle	Medium to long	
Facilitate capital access for formal enterprises (particularly MSMEs), using simplified procedures, lower interests, and longer repayment periods, while providing investment and financing advice	National, local	9Rs	Medium to long	
Prioritize the financing of collection and treatment of e-waste fractions of low market value and fractions containing CoC	National	Recycle	Short	
Offer affordable and suitable insurance for independent repair and refurbishing enterprises	Local	Repair, refurbish, remanufacture	Short	
Develop, pilot test and scale up novel business model solutions financing circularity gaps in the electronics value chain	Global, national, local	9Rs	Short	Businesses

5. CAPACITY DEVELOPMENT, AWARENESS RAISING AND ADVOCACY

Provide reliable sustainability information and guide consumer purchasing, use, EoU and EoL behaviour towards more circular electronics on the African market	National, local	9Rs	Medium to long	IGOs, CSO, researchers and academic institutes
Promote inclusion of the topic of circular economy in the curriculum on different educational levels	Local	9Rs	Short	
Raise awareness of negative impacts on human health and the environment from suboptimal, informal mining and e-waste treatment in Africa. Provide stakeholder-appropriate information and training programmes	Local	Reduce by design, recycle	Short	
Integrate a circular economy for electronics in global and regional forums and strengthen capacity development (e.g., GACERE, AMCEN, ACEA, ECOWAS, ACEN)	Global, regional	9Rs	Short	Policymakers and regulators
Promote proper e-waste collection, e-waste sorting and disposal using information campaigns and media	Local	Recycle	Short	
Integrate circularity into non-financial reporting and ensure due diligence of the electronic value chains	Global	9Rs	Medium to long	Brands and retailers
Develop capacity among brand owners and manufacturers (particularly among MSMEs) to shift towards more circular business models and stronger responsibilities	Local	9Rs	Short	

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APPENDIX A

Table A.1. EEE categories and examples of electric and electronic equipment, as defined by the Directive 2012/19/EU.

EEE CATEGORIES	NON-EXHAUSTIVE LIST OF ELECTRONICS
1. Temperature exchange equipment	Refrigerators, Freezers, Equipment which automatically delivers cold products, Air conditioning equipment, Dehumidifying equipment, Heat pumps, Radiators containing oil and other temperature exchange equipment using fluids other than water for the temperature exchange.
2. Screens, monitors, and equipment containing screens having a surface greater than 100 cm^2	Screens, Televisions, LCD photo frames, Monitors, Laptops, Notebooks.
3. 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.
4. Large equipment*	Washing machines, Clothes dryers, Dish washing machines, Cookers, Electric stoves, Electric hot plates, Luminaires, Equipment reproducing 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.
5. Small equipment	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, Calculators, Radio sets, 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.
6. Small IT and telecommunication equipment (no external dimension more than 50 cm)	Mobile phones, GPS, Pocket calculators, Routers, Personal computers, Printers, Telephones.

*This category can be further separated into 4a. Large equipment (excluding photovoltaic panels) and 4b. Large equipment (photovoltaic panels).

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