PBL Netherlands Environmental Assessment Agency

POTENTIAL EFFECTS OF DUTCH CIRCULAR ECONOMY STRATEGIES ON LOW- AND MIDDLE-INCOME COUNTRIES

The case of electrical and electronic equipment

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Potential effects of Dutch circular economy strategies on low- and middle-income countries: the case of electrical and electronic equipment

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Main Findings

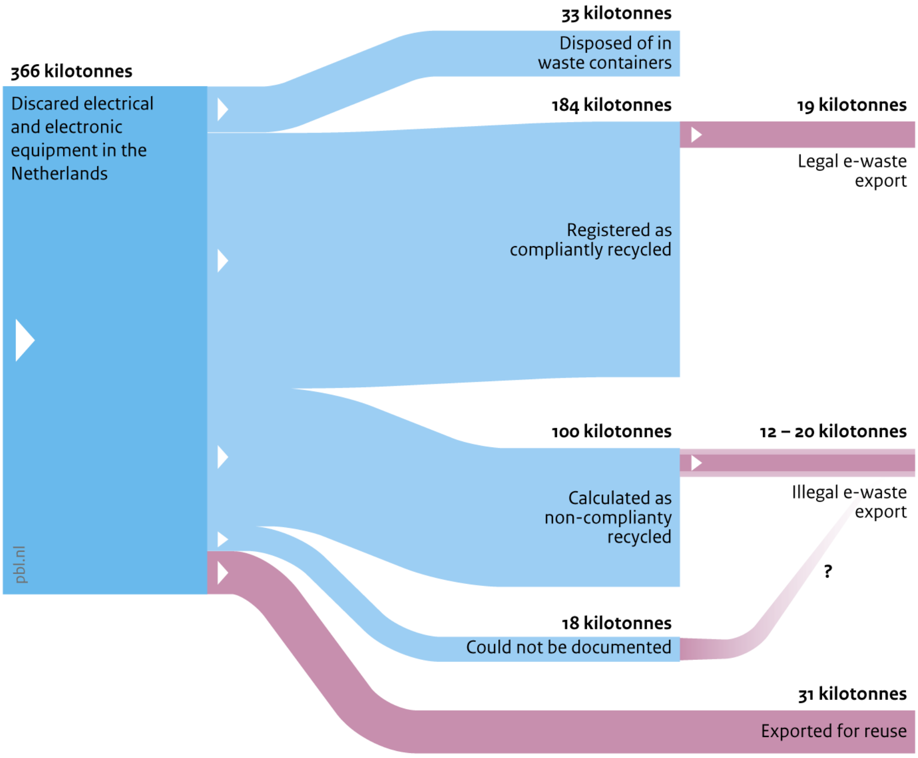
In its Government-wide Programme for a Circular Economy, the Netherlands presents its ambition to move away from a linear economy and towards a circular system by 2050. The overarching goals of this transition are to decrease and limit environmental pressures while addressing potential supply certainty risks for crucial resources. A successful transition from a linear to a circular economy will have consequences for global value chains, thus affecting people and the environment on a global scale. At the request of the Dutch Ministry of Foreign Affairs, this study by PBL Netherlands Environmental Assessment Agency explores the effects of Dutch circular economy strategies on low- and middle-income countries.

The effects vary per product group and type of strategy. The study focuses on the end-of-life electrical and electronic equipment (EEE). Electronic waste is the fastest growing waste stream around the world, and is associated with severe environmental and social consequences. The official methods and strategies of waste collection and recycling are barely keeping pace with the increasing volumes of discarded equipment, especially in low- and middle-income countries. On top of that, significant shares of discarded electronic products are traded internationally, mostly from high-income countries to low- and middle-income countries. The study discusses impacts (both positive and negative) of a range of circular economy strategies that target electrical and electronic equipment in the Netherlands on low- and middle-income countries, with a specific focus on Western Africa (i.e. Ghana and Nigeria), which is a large recipient of discarded electrical and electronic equipment. The analysis covers both non-functioning items referred to as e-waste (WEEE) and second-hand items (used EEE).

Around one fifth of discarded electronic equipment in the Netherlands is exported, around one quarter of which illegally

In 2018, 514 kt new electronic equipment was put on the market in the Netherlands and 366 kt was discarded. Around 50% of the discarded equipment was recycled in compliance with standards and regulation, and 20% was exported to countries both within and outside the EU. The remainder is undocumented, likely recycled outside of proper channels, or disposed of in municipal waste streams (Figure 1). There are various ways in which discarded equipment is exported, including both legal and illegal activities. In 2018, approximately 5% of discarded products (19 kt), such as washing machines, IT equipment and small household appliances, was exported for pre-processing or final processing abroad, mostly within the EU. These types of exports are regulated by the Dutch Producer Compliance Schemes, of which Wecycle is the largest. Roughly 8% (31 kt) of discarded products in 2018 was exported for reuse abroad. Around half of this 8% consisted of common household second-hand electronics that could be traced to Eastern European countries (mostly to the Czech Republic, Romania, Hungary and Bulgaria), while at least one third could be traced to countries outside the EU, mostly in Western Africa (e.g. Ghana and Nigeria). Finally, an estimated 3% to 5% was exported illegally (12–20 kt). This included e-waste mixed in with scrap metal, which most probably was exported to neighbouring EU Member States, and e-waste mixed in with second-hand electronics, which most likely went to Eastern Europe and Western Africa.

Figure 1
Dutch flows of discarded electrical and electronic equipment, 2018



Source: UNU/UNITAR, NWR

Trade in discarded equipment affects pollution, human development and resource efficiency abroad

Trade in second-hand electronics and e-waste has both positive and negative impacts in low- and middle-income countries. These impacts are essentially connected to the following three issues:

1. *Pollution*: electrical and electronic equipment contains many hazardous and toxic substances that can be released into air, water and soil if not handled properly. Pollution forms the underlying factor for public health impacts, most labour risks and environmental damage, including contributing to climate change. Women and children who are active in the e-waste value chain are particularly vulnerable to health risks.
2. *Human development*: large groups of people benefit in one way or another from the import of used EEE and e-waste, including access to affordable second-hand electronics and jobs associated with collection, repairing and dismantling. Different types of jobs carry different risks and benefits. For example, dismantlers and recyclers typically face the highest risks, while workers in repair and refurbishment usually earn the most.

3. *Resource efficiency*: resource efficiency refers to the number of products, the materials or the services that can be derived from a particular amount of resources. In relation to e-waste this refers to the actual material recovery rates as well as the economic value. It also refers to how long materials remain in use, for example in the sense that reuse or repair is more resource-efficient than dumping, burning or recycling after first use. The transboundary trade in used EEE and e-waste in its current form is resulting in material losses for exporting countries, as potential secondary materials leave the economy. On the other hand, recycling does not mean that all materials can be recovered; for example, the recovery of most rare earth elements (REEs) is bound by physical, technological and economic limitations.

The consequences of the transboundary trade in discarded electronics from the Netherlands, are probably most extensive for Western Africa (i.e. Ghana and Nigeria), as the share of discarded electrical and electronic equipment that is exported to Western Africa is much larger than to other regions, while only 0.4% of e-waste domestically generated in Western Africa in 2018 is documented to have been managed in an environmentally sound manner.

Effects of circular economy policies on low- and middle-income countries can be both positive and negative

Circular economy policies can be organised along the so-called R-ladder and clustered in broad strategies that are aimed at reducing the amount of material input (narrowing loops); keeping products or materials in use longer (slowing loops); and recovering energy or recycling materials and preventing losses (closing loops) (Table 1). The impacts of Dutch circular economy policies that target electrical and electronic equipment on low- and middle-income countries depend on 1) the type of circular economy strategy; 2) if and how low- and middle-income countries are part of the circular economy loops of the Netherlands; and 3) the way e-waste is managed abroad. These impacts can be both positive and negative and differ for pollution, human development and resource efficiency.

Circular economy strategies can reduce exports of second-hand products, having several negative impacts

All three circular economy strategies (Table 1) may reduce the number of discarded products available for export, albeit in different ways. Policies aimed at narrowing loops and slowing loops are expected to reduce the availability of used EEE for export as products are kept in use longer or are not purchased at all. Moreover, when products are used longer, they might be less suitable for further lifetime extension abroad. Transboundary trade in e-waste is currently restricted under the Basel Convention. With policies to close loops aimed at optimal waste processing in the EU, closing loops could also help limit this restricted trade. As strategies on narrowing loops mainly affect new electronics entering the market, in the short term, the largest effect on trade flows can be expected from strategies under slowing loops and closing loops.

Reduced exports of used EEE to low- and middle-income countries reduces availability and access to quality second-hand products, including mobile phones, household appliances and laptop computers. Reduced exports also affects jobs in the repair and refurbishment industry and, as these products eventually end up as waste, also has an impact on those in waste management.

Table 1: Circular economy measures clustered in three strategies

CE strategy	Levels of the R-ladder	Examples of types of measures	Affecting
Narrowing loops	R1. Refuse and Rethink R2. Reduce	Reducing material use through the sharing of products, using alternative materials or forgoing certain products	New electronics
Slowing loops	R3. Reuse R4. Repair and Refurbish	Extending use phase and lifespan of products, e.g. through repair or refurbishment, repair cafes, lowering VAT on repairs, buying second-hand	Second-hand electronics
Closing loops	R5. Recycle R6. Recover	Recycling product parts and recovering materials and energy for reuse	E-waste

On the positive side, reduced exports could result in less pollution in receiving countries, although consumers in low- and middle-income countries are unlikely to simply stop using electrical and electronic equipment. This means that reduced availability of second-hand products from the EU could create higher demand for cheaper but lower quality products from other regions, which are reported to break down faster and to be more difficult to repair. As a result, instead of lower pollution levels, reduced exports of used EEE could in fact result in an increase in pollution, thus limiting or even completely negating the initial positive effects. More fundamental strategies, for example in terms of design, can make recycling or repair easier and less harmful to the environment and human health. Cross-cutting measures such as redesign are relevant for all three strategies.

Including non-EU countries in the circular economy loops of the Netherlands may create mutual benefits as well as present challenges

There are several ways for low- and middle-income countries, such as Ghana and Nigeria, to become part of the circular economy of the Netherlands. This study discusses four scenarios. Refurbishment of used EEE abroad could create employment opportunities and improve resource efficiency, but would also need to deal with the side-effect of the generation and current mismanagement of e-waste. Increasing the exports of used EEE for reuse abroad can improve access to quality products as well as achieve higher value retention, but also needs a strategy to improve waste management, as the used EEE eventually becomes e-waste. Exporting e-waste to Western Africa for processing and material recovery is illegal, in theory it is only possible if environmentally sound e-waste management can be ensured. Finally, the collection of e-waste abroad and shipping it to Europe to recycle and recover valuable materials and the safe processing of the remaining fractions could have benefits for pollution. However, this approach faces practical barriers and it is not clear how to finance the safe processing of discarded items that have too little material value. Under all four scenarios, the level of success will depend on finding ways to work with the informal sector.

Interventions in the e-waste value chain will also affect human development

There is enormous added value in the transboundary trade in used EEE for human development in the Global South, for example in terms of jobs or access to affordable electronics. This is one of the main reasons that so much discarded equipment is exported to countries such as Ghana and Nigeria.

Furthermore, giving used EEE a second life abroad can be a resource-efficient strategy, in terms of value retention. The potential benefits are nevertheless accompanied by the severe negative impacts of current waste processing practices. Strategies that ignore these dilemmas risk harming people and the environment, thereby undermining the achievement of the Sustainable Development Goals. In addition, if the role of the trade in used EEE for local communities is not considered, interventions will likely fail to address the drivers of e-waste generation and processing in low- and middle-income countries. This means that misguided policy interventions could both have unwanted side-effects and achieve very little in limiting e-waste generation and processing under unsafe conditions.

A just transition requires an inclusive approach

Ensuring that the transition to a circular economy does not further marginalise communities that benefit from e-waste or used EEE will require an inclusive strategy. This entails recognition of the role the e-waste value chain plays with respect to the various needs, challenges and opportunities for people in low- and middle-income countries. Mutual benefits are possible if strategies include local workers and small enterprises already active in informal e-waste collection, sorting and dismantling. Circular economy strategies that fail to understand and address the interlinkages between the dimensions of human development, pollution and resource efficiency of the e-waste challenge, will at best miss an opportunity for an inclusive transition, and at worst undermine the achievement of the UN Sustainable Development goals and exacerbate environmental degradation.

Work with the informal sector, not against it

If strategies mainly focus on banning informal e-waste processing without creating alternative employment opportunities, workers and communities that currently make a living from e-waste can be negatively affected. This approach will not solve the problem but shift it elsewhere, as it does nothing to address the increasing domestic generation of e-waste in Western Africa. For these reasons, it is important to recognise the informal system already in place, on which many people’s livelihoods depend. Instead of trying to replace these jobs, informal waste collectors, dismantlers and recyclers can be supported to adopt safer techniques and gain access to better equipment.

Precautions are needed to decrease external costs

To benefit from the potential positive effects and mitigate any negative effects of a circular economy, a sound understanding of the existing, complex situation and challenges is required. This also calls for a clear perspective on what precautions are necessary to prevent unwanted consequences. In countries with high poverty rates, a large informal labour force and no enforcement of environmental regulations, costs are easily externalised to the detriment of the environment and public health. All strategies examined in this study require investments in safe and environmentally sound local e-waste management; robust registration, reporting and monitoring systems for exports of discarded EEE; and effective enforcement of existing regulations as well as further restrictions of the export of worthless and hazardous fractions.

1 Introduction

In the Government-wide Programme for a Circular Economy, launched in 2016, the Netherlands describes its ambition to move away from a linear economy towards a circular system by 2050 (Ministry of IenM and Ministry of EZ, 2016). The overarching goals of this transition are to decrease and limit environmental pressures while addressing potential supply security risks for crucial resources. Furthermore, with the transition towards a circular economy, the Netherlands aims to contribute to the realisation of the Sustainable Development Goals (SDGs; UN, 2015). A circular economy may provide economic opportunities, contribute to a cleaner environment and make countries less dependent on domestic and imported scarce natural resources. A successful transition requires actions throughout the whole value chain: from the extraction of raw materials to product design, manufacturing, usage, repair, reuse and, finally, recycling.

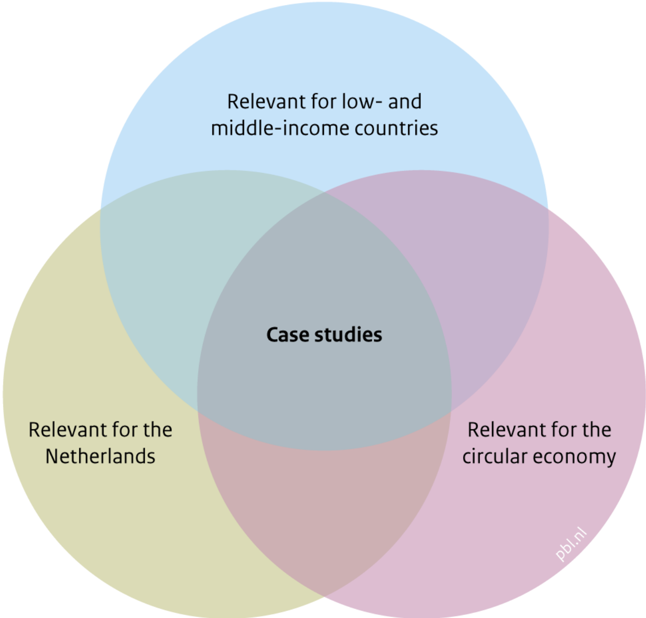
To this end, policies are being developed that focus on increasing efficiency, substitution of scarce or non-renewable resources, and technological and social innovation. While several aspects of a circular economy transition in the Netherlands will most likely affect Dutch businesses, consumers and citizens, little is known about the potential impacts on other countries that are connected through international value chains (De Ridder, 2017; IEEP, 2019; Rademaker, 2017). Several trade flows will probably be affected, including the trade in primary and secondary raw materials, waste, second-hand products, and services (Van der Ven, 2020). Existing knowledge on affected trade flows and the related impacts abroad, however, is limited and fragmented. Furthermore, whether impacts will be positive or negative is highly context-specific, as is their level of severity (Circle Economy, 2020). The impacts differ per product group and its position in the circular economy, depending on the economic and ecological value of the product in question (Lucas et al., 2016). A focus on specific materials or products is advisable (Circle Economy, 2020), while scenario analysis can help to consider the various effects (Lucas et al., 2016).

At the request of the Dutch Ministry of Foreign Affairs, PBL Netherlands Environmental Assessment Agency has explored the effects of Dutch circular economy policies on low- and middle-income countries. Different case studies are being conducted, each focusing on specific types of materials or products. The materials or products were selected on the basis of their 1) relevance for low- and middle-income countries in terms of impacts; 2) relevance for the Netherlands; and 3) relevance for the circular economy (Figure 1.1). This report focuses on end-of-life electrical and electronic equipment (EEE). We distinguish between e-waste and 'used EEE'. E-waste stands for waste electrical or electronic equipment. Used EEE is electrical and electronic equipment that is available for reuse.

PBL Circular Economy Research
In the Netherlands, the transition to a circular economy is increasingly taking shape, both in society and with respect to the government. PBL studies support this process using various forms of research. PBL analyses the impact of policy on the environment and the economy, identifying opportunities and obstacles for citizens and businesses, and exploring which policy instruments could lead to a circular economy. At the request of the Dutch Government, PBL takes the lead in a national research programme aimed at monitoring and evaluating the progress of the transition process.

For more information, please see: www.pbl.nl/en/topics/circular-economy

Figure 1.1
Criteria for case study selection



Source: PBL

E-waste is one of the fastest growing waste streams, globally, resulting from the high consumption rate of such equipment, short product lifecycles, and a lack of repair options (Forti et al., 2020). On a global level, e-waste increased by more than 20% between 2015 and 2019, amounting to 53.6 Mt in 2019, and is projected to increase further to 75 Mt by 2030 (Forti et al., 2020) and 110 Mt by 2050 (Parajuly, 2019). Electrical and electronic equipment includes many valuable metals and other materials that are important for the Dutch and European economy and, if recycled properly, could be used as secondary materials. However, the official methods and strategies of waste collection and recycling are barely keeping pace with global consumption rates. In 2019, less than 20% of global e-waste was officially documented as having been properly collected and recycled. The remaining 80% is expected to have been dumped, traded illegally, or recycled in a non-environmentally sound way (Forti et al., 2020).

Significant shares of e-waste are traded internationally, mostly from the Global North to countries in the Global South, with Europe having the highest formal collection and recycling rate (42.5%) and Africa the lowest (0.9%). Informal treatment of e-waste is associated with severe health risks as a result of exposure to hazardous substances and environmental pollution. It may also be the cause of valuable resource losses as a result of inefficient recycling methods. At the same time, e-waste that is exported from the Netherlands and the EU to low- and middle-income countries is important for economic development and human well-being, as it provides jobs in repair, collection and recycling, as well as access to quality products such as basic kitchen appliances, mobile phones and laptops. However, while e-waste labelled for reuse can get a second life abroad, substantial shares are no longer functioning. Furthermore, the second-hand equipment eventually ends up being dumped or dismantled without adequate regulation or infrastructure to handle it in a responsible and efficient way (Heacock et al., 2016).

To assess the impact of circular economy policies that target electrical and electronic equipment (EEE) on low- and middle-income countries, the study is divided into four parts.

- Chapter 2 focuses on the trade in e-waste. This includes a discussion of the definition of e-waste; the relevant regulatory frameworks that apply to used EEE and e-waste; and the most recent data on used EEE and e-waste exported from the Netherlands.
- Chapter 3 discusses socio-economic and environmental impacts (both positive and negative) of existing trade flows of e-waste from the Netherlands. This analysis focuses on impacts that arise from reuse, repair and recycling in Ghana and Nigeria, two major importing countries of used EEE and e-waste from the Netherlands. Based on literature review and expert consultation, three main impact areas are identified and described: pollution, human development and resource efficiency.
- Chapter 4 discusses the potential effects of a transition towards a circular economy in the Netherlands on low- and middle-income countries. Various scenarios are analysed with respect to their potential effect on the three impact areas discussed in Chapter 3. The scenario analysis looks at different types of circularity strategies, and ways of including low- and middle-income countries in the circular economy loops of the Netherlands. Main challenges are identified and discussed, for each scenario.
- Finally, Chapter 5 synthesises the results from Chapter 4 by discussing the preconditions for low- and middle-income countries to benefit from a circular economy transition in the Netherlands, as well as those to mitigate potential negative effects.

2 Trade in discarded equipment

Electrical and electronic equipment (EEE) that has been discarded is being traded on a global level, with significant flows from high-income countries to low- and middle-income countries. This chapter discusses transboundary flows of discarded EEE from the Netherlands, either in the form of second-hand equipment (i.e. used EEE) or as genuine waste, including the regulatory landscape and recent trade flows.

2.1 Discarded electrical and electronic equipment

E-waste and used EEE

The definition of e-waste has been a topic of debate for many years. The absence of an internationally agreed definition is partly the reason for the lack of a shared understanding of the size of global e-waste production and trade flows. Differing definitions mean that discarded products considered e-waste in one country may not be regarded as such in another. Furthermore, definitions of e-waste do not include large, fixed installations in factories, for instance, or large products that contain electronic or electrical components, such as vehicles. Finally, the term e-waste when undefined can be misleading since it disregards the inherent value of the discarded products. In 2019, the total global value of all recoverable raw materials in e-waste — including gold, silver, palladium, copper, aluminium and iron — was estimated at USD 57 billion (Forti et al., 2020).

Various definitions of e-waste exist:

- In 2015, at its 12th meeting, the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal adopted technical guidelines on transboundary movements of electrical and electronic waste and used electrical and electronic equipment, which contain the following definition: ‘Electrical or electronic equipment that is waste, including all components, sub-assemblies and consumables that are part of the equipment at the time the equipment becomes waste’ (SBT, 2015).
- The Solving the E-Waste Problem (StEP) initiative hosted by the United Nations University defines e-waste as ‘all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of reuse’. Items qualify for inclusion if they have ‘circuitry or electrical components with power or battery supply’ (StEP Initiative, 2014).
- The Waste Electrical and Electronic Equipment (WEEE) Directive of the European Parliament and of the Council (Directive 2012/19/EU) defines e-waste to consist of electrical and electronic equipment (EEE), ‘including all components, sub-assemblies and consumables which are part of the product at the time of discarding’ (EU, 2012).

In this report, we distinguish between e-waste and ‘used EEE’. E-waste stands for waste electrical or electronic equipment (WEEE), including all components, sub-assemblies and consumables that are part of the product at the time of discarding.

Used EEE is electrical and electronic equipment that is available for reuse. Electronics, electrical equipment, electronic products and electrical appliances all refer to products that are classified as EEE.

EEE classification

There are many types of electrical and electronic equipment (EEE) and e-waste. UNU-KEYS is the central product classification for making mass balances of e-waste per country. The UNU-KEYS classifies 54 product types that, per category, share similar functions, comparable average weight, comparable material composition (in terms of hazardous substances and valuable materials), end-of-life characteristics, and lifetime distributions (see Appendix B).

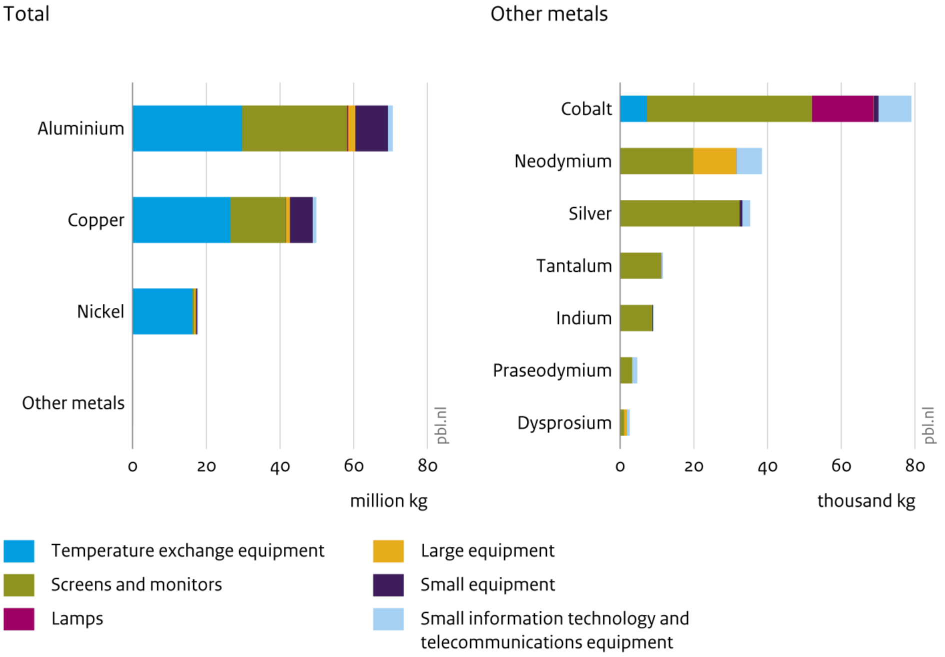
In the EU, reporting on EEE that is brought onto the market or is collected and recycled according to the WEEE Directive (see Section 2.2.) is done in six categories:

1. *Temperature exchange equipment (TEE)*, such as refrigerators, freezers, air conditioners, and heat pumps.
2. *Screens and monitors and equipment containing screens having a surface greater than 100 cm^2*, such as televisions, monitors, laptops, notebooks, and tablets.
3. *Lamps*, such as fluorescent lamps, high intensity discharge lamps, and LED lamps.
4. *Large equipment* (external dimension greater than 50 cm), household appliances, such as washing machines, clothes dryers, dishwashing machines, electric stoves, large printing machines, copying equipment, and photovoltaic panels. This category is often split for photovoltaic (PV) panels.
5. *Small equipment* (external dimension no more than 50 cm), such as vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, electrical and electronic toys, small electrical and electronic tools, small medical devices, small monitoring, and control instruments, household appliances luminaires, musical equipment and toys.
6. *Small information technology and telecommunications equipment* (external dimension smaller than 50 cm), such as mobile phones, Global Positioning System (GPS) devices, pocket calculators, routers, personal computers, printers, and telephones.

E-waste reporting systems, legislation and take-back schemes do not cover any type of battery, accumulators, or electrical components of vehicles. Batteries embedded in e-waste are often collected together with the e-waste but should be separately reported and legislated. For batteries and end-of-life vehicles, specific legislation and take-back schemes have been set up.

Transboundary movement of e-waste and used EEE is also registered in trade statistics. For each product, its foreign trade (import and export) is registered under the Combined Nomenclature (CN) in the European Union. The exported used EEE is often recorded with the same code as its new equivalent, due to the absence of used EEE codes and e-waste codes under the CN. Another classification system that is used for waste permits in the Netherlands is the List of Waste (LoW) and several hazardous components in the reporting under the Basel Convention. Illegal shipments of e-waste and e-waste that is illegally mixed in with other waste streams are not registered. This is done on purpose to avoid compliance requirements and inspections.

Figure 2.1
Metals in electrical and electronic equipment per category, 2016 – 2018



Source: CML/CBS 2020

E-waste is a potentially important source of valuable materials
Electrical and electronic equipment (EEE) contains several valuable materials that, if recycled properly, could be used as secondary materials. The value of raw materials in global e-waste generated in 2019 is estimated at USD 57 billion (Forti et al., 2020). The materials contributing most to this value are iron, copper, and gold, but there are many other materials and rare earth elements in electronics. Despite the high value of such materials in e-waste, less than 20% of global e-waste is collected and recycled, from which around USD 10 billion worth of materials are recovered (Forti et al., 2020). For the EU (also including Switzerland, Norway and Iceland) this is estimated at 52% (Baldé et al., 2020b). The e-waste that is not compliantly recycled in the EU is estimated to have represented a loss of material worth of more than EUR 171 million in 2016 (Magalini and Huisman, 2018). Furthermore, while common commodity metals, such as steel, magnesium and copper, can be recovered relatively easily, as these are often used in relatively simple applications, the small amounts of metal in e-waste are much more difficult to recover because they are often just one among up to 50 elements. The degree to which metals can be separated affects the economics of recycling, and the increasing complexity of recovering materials from electronics also becomes more challenging. For the recycling operation, the choice of process is a technological optimisation puzzle that is based on economics and physics, which is at least partly driven by the changing market value of certain metals and their high-end alloy products (Reuter et al., 2013).

2.2 Regulatory frameworks for the trade in discarded equipment

Since the early 2000s, e-waste has received increasing attention from policymakers. This attention initially centred around the shipment of e-waste to low- and middle-income countries, where it was treated mostly under inferior conditions, with negative impacts on workers and the environment. The rapid increase in e-waste flows, in recent years, has stirred attention for the materials in e-waste. This includes competition for scarce resources and the fear of running out of critical materials that cannot easily be substituted. Even inexperienced consumers have become aware of the short lifetimes and unrepairability of their products. And with the obvious wasting of resources, questions have arisen around the competition between various industries for the limited resources, in the same way as the fear of running out of critical materials, which cannot easily be substituted.

In response to these developments, governments around the world have established both international and national e-waste policies and regulatory frameworks and legislation to deal with the increase in end-of-life electrical and electronic equipment. Such policies lay out plans and indicate, often in a non-binding manner, what can be achieved for a society, institution, or company. Legislation is implemented at national or municipal levels and describes how it should be enforced by regulators. For the Netherlands, transnational (the Basel Convention) and EU frameworks (the WEEE Directive and waste shipping regulation) are relevant and translated into national policies.

Current e-waste policies mostly focus on collection and recycling
In their policies and legislative efforts, policymakers in both industrialised and emerging economies mostly focus on developing financing and awareness schemes to improve participation in the private sector and of individual consumers. The objective being to ensure higher collection and recycling rates and generate sufficient revenue to meet costs of treatment. Most legislative instruments concentrate on resource recovery through recycling and countermeasures against environmental pollution and human health impacts caused by waste. The reduction in e-waste volumes and substantive repair and reuse of EEE, so far, has been limited. Only recently, e-waste-related policies, legislation and resulting regulations have also started to consider the more fundamental aspects of design and production. The projected doubling of the annual e-waste generation for the next 30 years (Parajuly, 2019), requires a reconsideration of the present approaches or at least a substantial enforcement of current legislation and regulations.

The Basel Convention restricts cross-border movement of hazardous waste
On a transnational level, e-waste is dealt with under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, which entered into force in 1992. The Basel Convention was signed by 187 countries. It affirms that, in order to protect human health and the environment, hazardous waste should not be traded freely like ordinary commercial goods. Therefore, it established a written notification and approval process for all cross-border movements of hazardous wastes. In 2002, the convention started to address e-waste issues that include, among other things, environmentally sound waste management, prevention of illegal trafficking to low-income countries, and building capacity around the globe to better manage e-waste. Furthermore, technical guidelines on the transboundary movement of e-waste, in particular regarding the distinction between waste and non-waste, are subject to continuous fine-tuning.

The Basel Convention does not address e-waste as such, but classifies hazardous waste in terms of the substances contained in the waste material, listing a threshold limit for each identified hazardous substance. Furthermore, it establishes regulatory exemption on equipment that is destined for reuse (i.e. used EEE).

The Convention text has been subject to various amendments since its adoption. The Ban Amendment entered into force on 5 December 2019. This amendment prohibits the transboundary movement of hazardous waste from so-called Annex VII parties (OECD countries, EU Member States and Liechtenstein) to non-Annex VII parties. Hazardous waste includes waste covered under the Convention that is intended for final disposal, reuse, recycling or recovery.

There is ongoing discussion under the Basel Convention about the definition of waste — whether or not something is intended for reuse. Most shipments of equipment for reuse are unrestricted, unless the exporting or importing country explicitly bans shipment of such used products. For the enforcement by customs and port authorities it is difficult to distinguish between used and brand new equipment, because there are no trade codes specifying this distinction, and shipments typically are not accompanied by documentation on any included used EEE or e-waste. Often, there are only a few customs officials on duty at any one time, in centres such as Hamburg, Rotterdam or Antwerp, and they must decide quickly when confronted with large numbers of containers of electronic equipment. As a result, when they lack the information needed to base their decision on, they mostly follow their own interpretation based on experience when deciding whether a shipment contains e-waste or not. Although the 14th Conference of Parties to the Convention (COP14) adopted the revised technical guidelines on transboundary movements of e-waste and used EEE on an interim basis, final consensus has not been reached concerning the definition of e-waste. Voluntary national reporting by Parties to the Convention currently stands at less than 50% of signatories.

The Bamako Convention

The Bamako Convention on the Ban on the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa is a treaty of African nations that prohibits the import into Africa of any hazardous waste, including radioactive waste. Furthermore, it prohibits the incineration or dumping into oceans and inland waters and aims to ensure environmentally sound management of waste, to minimise the transboundary movement of hazardous waste between African nations, and to establish the precautionary principle as stipulated in the Rio Declaration[1] (Organisation of African Unity, 1991). The Bamako Convention was adopted in 1991 and came into force in 1998 with the aim of protecting human and environmental health. It is a response to Article 11 of the Basel Convention, which encourages parties to enter into bilateral, multilateral and regional agreements on hazardous waste, to help achieve the objectives of the convention. To be effective, countries must implement the import ban in national legislation and notify the Basel Convention of additional restrictions.

[1] Principle 15: In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (UNCED, 1992).

EU WEEE Directive
The Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) is a key element of the EU environmental policy on waste. The Directive seeks to induce design modifications that make e-waste easier to dismantle, recycle and recover. Furthermore, it plays an important role in reducing the dispersion of hazardous substances into the environment by seeking not only to regulate the use of hazardous substances in equipment but also controlling the way that older equipment is disposed of at the end of its life. The removal of hazardous substances reduces the contamination of recyclates and, thus, eases recycling and disposal of these residues.

All e-waste collected, regardless of origin or collection method, must be reported. The European standardisation organisation has developed treatment standards for ensuring a minimum environmental performance, but these have not yet been adopted by the European Commission, although a few countries, such as the Netherlands, are implementing them. Moreover, two clear targets have been set in response to diverging target-setting methods by EU Member States: from 2019 onwards, the minimum collection rate to be achieved is 65% of the average weight of EEE that was placed on the market in the three preceding years, or alternatively 85% of the WEEE generated. Only Croatia (83%) and Bulgaria (79%) are already above the 65% target (Baldé et al., 2020b).

EU Waste Shipment Regulation
In 2006, the EU transposed the Basel Convention into European regulation with the European Waste Shipment Regulation (WSR). The WSR implements the international obligations under the Basel Convention and includes the internationally agreed objective that waste shall be disposed of in an environmentally sound manner. How and what types of waste can be exported under the WSR is contingent on a few factors: a) the intended destination, b) the purpose of export (reuse, recovery or disposal) and c) the type of waste being exported. Similar to the Basel Convention, which it builds on, the WSR divides waste into three primary categories, i.e. waste presenting low risk for human health and the environment ('green-listed' waste) shipped for recovery (exporter has to follow the so-called Article 18 procedure[2]), waste presenting enough risk to justify control, or 'green-listed' waste shipped for disposal (export requires prior written notification and consent), and hazardous waste (export is prohibited).

Unlike the Basel Convention, however, the WSR classifies waste by components, meaning that used and end-of-life electronics fall into one of the three WSR categories depending on their components (Salehabadi, 2013). Importantly, as is the case with the Basel Convention, many of the key components in used EEE and e-waste are not listed under the WSR. The Regulation forbids the shipment of hazardous wastes from EU to non-OECD countries. It does however allow the shipment of non-hazardous waste to other countries, as long as that waste is exported for the purpose of recovery. Moreover, if items are dismantled in the country of origin, what remains will often be categorised as green-listed waste, thus exempting an exporter from having to notify the authorities.

[2] The waste has to be accompanied by a fully completed form (contained in Annex VII of the WSR) and signed by the person who arranges the shipment. The person who arranges the shipment will have to enter into a contract with the consignee for recovery of the waste, which states the obligations and responsibilities, in case either shipment or recovery cannot be completed.

Dutch national implementation
In 2014, the Dutch Government implemented the EU WEEE Directive into national legislation and regulation (Ministry of IenM, 2014). Some specific implementation measures included:

- In 2015, the *Nationaal (W)EEE Register* was created, which registers all official data on electrical and electronic equipment placed on the market and e-waste collection and treatment. Monitoring of used EEE exports was conducted in a pilot project, but reporting on exports for reuse will be mandatory from 2021 onwards.
- As of 1 July 2015, discarded EEE should be processed according to the WEEELABEX standards (Waste Electric and Electronic Equipment LABel of Excellence). The standards were introduced in April 2011, followed by the creation of an official WEEELABEX organisation to help implement the standards across Europe. On an EU level, the follow-up standard of WEEELABEX is CENELEC (European Committee for Electrotechnical Standardization), which is the EU standardisation for electronics.
- Between 2016 and 2020, the organisational setting of a multi-stakeholder platform was defined in the Dutch implementation law which delineates a monitoring council (*monitoringsberaad*), representing all actors involved in e-waste management (i.e. producers, recyclers and government authorities).
- In late 2019, *Stichting OPEN* was founded by 2000 EEE producers, representing 80% of the Dutch EEE market. The objective of this non-profit organisation is to achieve the legal collection targets and to make e-waste circular.

Implementation of the Basel Convention on Member State level is included in the EU Waste Shipment Regulation (European Council, 2006). The monitoring of transboundary movement of hazardous e-waste and hazardous components from dismantled e-waste is carried out in the Netherlands, in accordance with this regulation, by Rijkswaterstaat, and inspections are conducted by the Dutch Human Environmental and Transport Inspectorate (ILT), police, customs and port authorities.

2.3 Trade flows from the Netherlands

Transboundary flows of e-waste and used EEE have become a major concern for both exporting and importing countries. For exporting countries, valuable resources are dissipating and not made available for the domestic recycling market. In addition, if e-waste exports are illegal or undocumented, this hampers the achievement of national e-waste collection and recycling targets. In case illegal e-waste is exported to non-OECD countries, which typically do not have a recycling infrastructure, this is in violation of the Basel Convention. For countries importing illegal e-waste, a recycling infrastructure and the necessary financing mechanisms to properly depollute (i.e. remove hazardous substances) and reclaim all valuable materials are lacking.

Trade in discarded EEE generally goes from high- to low-income countries
Per inhabitant, most e-waste is generated in high-income countries. While most e-waste is shipped from high-income to low- and middle-income countries, in some cases regional export of e-waste also occurs. There is also evidence of high value components, such as printed circuit boards that have a high concentration of gold, being transported from low- and middle-income countries to high-income countries to high-tech gold smelters. The less valuable components of e-waste and the ones that contain hazardous substances are often not shipped but are processed in the informal sector. E-waste export destinations are dynamic over time. Previously important e-waste importers, such as China, are increasingly exporting to other countries in Southeast Asia (Lepawsky, 2015).

The transboundary movement is also dynamic over time, due to regulatory and social changes. One example are the processing operations that rapidly shifted from China to Southeast Asian countries, such as Thailand, Malaysia and Vietnam, following China's import ban on waste in 2018 (Forti et al., 2020).

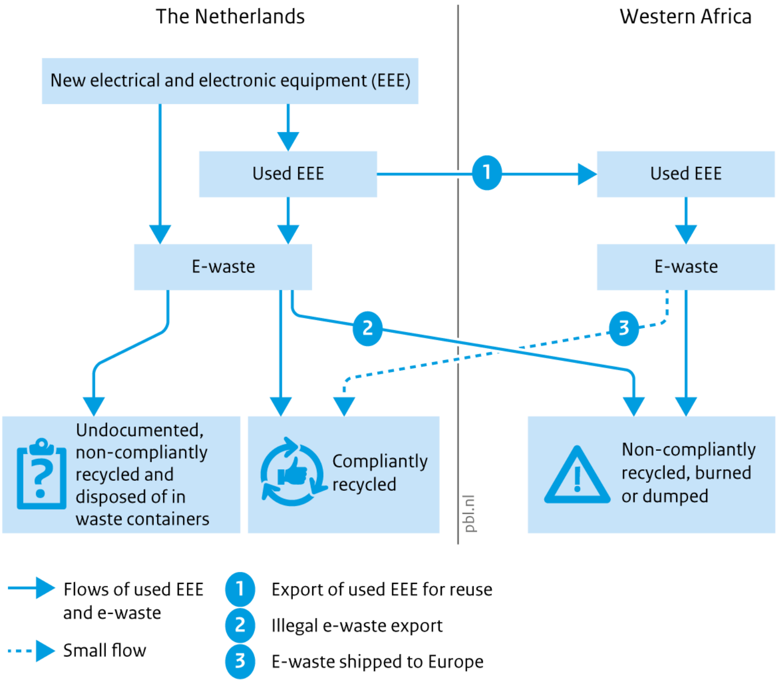
Trade in e-waste and used EEE in 2018 is estimated to have been between 7% and 20% (4–11 Mt) of the globally generated 53.6 Mt in e-waste (Forti et al., 2020). Around 15% of used EEE was exported from the EU, mainly for reuse (BIO Intelligence Service, 2013). Roughly 30% of the exported used EEE consisted of not functioning material or material susceptible to breakage during transport due to improper packaging (Huisman et al., 2015; Odeyingbo et al., 2017). Another study found that, in 2012, around 9.5 Mt of e-waste was generated, and 1.3 Mt left the EU as undocumented exports (Odeyingbo et al., 2017). The main economic drivers behind these exports were reuse and repair and not the dumping of e-waste, as functioning products have a much higher value than raw materials. Most e-waste and used EEE was exported to Africa and Asia (Odeyingbo et al., 2017). In a limited number of cases, the Middle East was also reported as a destination. Analysis revealed that e-waste was also transported from Western to Eastern Europe (Huisman et al., 2015).

Discarded EEE is exported from the Netherlands in various ways
Used EEE and e-waste is both legally and illegally exported from the Netherlands. Three main trade routes can be identified:

- **Legal e-waste exports**: E-waste can be exported for dismantling, depollution, and final treatment by a certified recycler in the EU. This trade is legal, and quantities are registered in the *Nationaal (W)EEE Register* and included in official reporting under the WEEE Directive.
- **Illegal e-waste exports**: It is often cheaper to treat e-waste illegally without considering depollution (i.e. the removal of hazardous substances) and only focusing on the valuable materials. There are three general ways of shipping e-waste illegally: 1) it is exported as unmixed, homogenous e-waste that will not be treated by a certified recycler in the receiving country; 2) the waste is mixed in with scrap metal that is subsequently exported under a scrap metal trade code; and 3) non-functioning items are mixed in with functioning items (or used EEE) that is exported for reuse.
- **Export of used EEE for reuse**: Second-hand products can be exported to other countries, thereby not becoming e-waste in the Netherlands. These exports are driven by a strong demand for second-hand goods in low- and middle-income countries. The exported goods may consist of professional equipment, often high-end reuse, as well as regular consumer equipment. These goods may be exported through legal refurbishing companies. There is also the informal collection of used EEE, such as from the street, charity shops, and online second-hand trading platforms. After being collected, the goods are sometimes transported in vans to Eastern European countries (EU and non-EU), shipped to Africa in containers or loaded into second-hand vehicles. The export of used EEE to non-OECD countries is legal under the Basel Convention and the WSR if it concerns functioning products, is properly declared and provided the recipient country does not have an import ban on such specific used EEE equipment.

For low- and middle-income countries, the influx of electronics consists of legal used EEE imports, and illegal e-waste imports (see Figure 2.2). Furthermore, a very small share of e-waste (i.e. mobile phones and laptops) is reshipped, mostly from Western Africa to Europe, where it is compliantly recycled by companies such as Closing the Loop, Close the Gap, Umicore and Boliden.

Figure 2.2
Current flows of used EEE and e-waste between the Netherlands and Western Africa

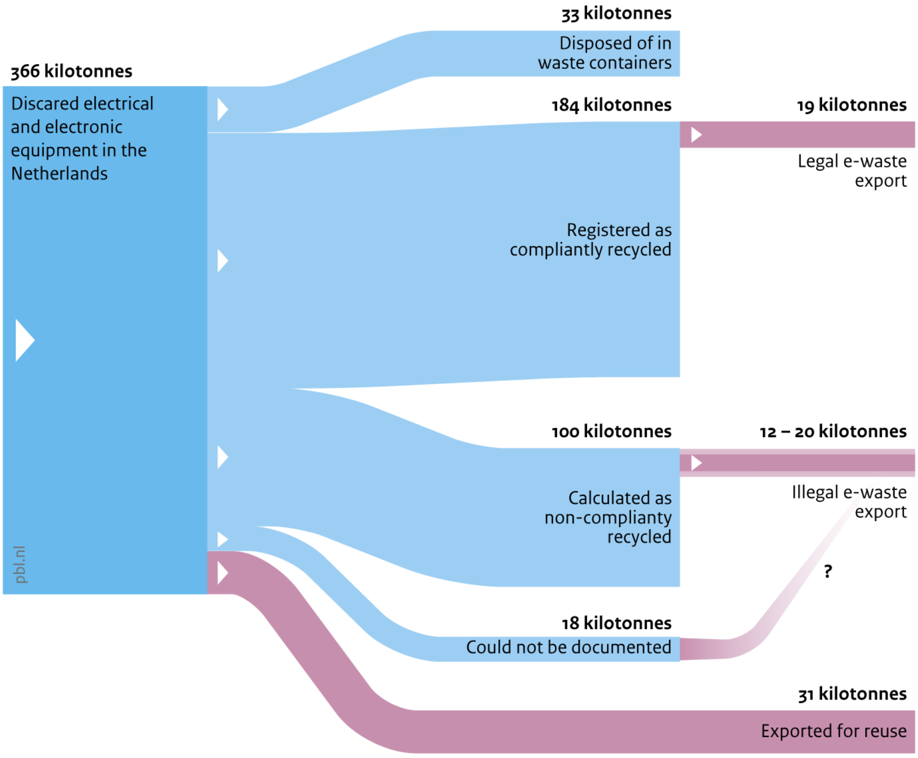


Source: PBL

Around 50% of discarded EEE in the Netherlands is non-compliantly recycled, incinerated or shipped abroad

Figure 2.3 shows Dutch flows in discarded EEE in 2018. Between 2010 and 2018, the total in electrical and electronic equipment (EEE) put on the market in the Netherlands increased by almost one third, from 387 kt in 2010 to 514 kt in 2018, while discarded EEE increased by 13% from 324 kt in 2010 to 366 kt in 2018 (Baldé et al., 2020a). During the same period, the share of discarded EEE that was registered as WEEE collected and compliantly registered in the *Nationaal (W)EEE Register* increased from 39% in 2010 to 50% in 2018. Still, the Netherlands has not achieved the 65% EEE POM nor the 85% WEEE Generated collection targets for 2019 under the EU WEEE Directive (Baldé et al., 2020a). The greatest share in discarded EEE in 2018 was for large equipment, followed by small equipment, screens and monitors and temperature exchange equipment. While the total weight of screens and monitors decreased since 2010, for photovoltaics it increased by more than 1300%. Still, the total weight of discarded photovoltaics is relatively low, mainly due to the long lifespans of the equipment. Approximately one quarter of EEE discarded in 2018 was non-compliantly recycled. This means that large amounts of discarded EEE continued to be traded and remained unregistered. Finally, another quarter was disposed of in municipal waste streams (9%), exported for reuse (8%), or could not be documented (6%). Equipment disposed of in waste containers, mostly comprising of small IT devices, lamps, and small equipment, ended up in waste incineration with their materials unrecovered.

Figure 2.3
Dutch flows of discarded electrical and electronic equipment, 2018



Source: UNU/UNITAR, NWR

Around one fifth of discarded EEE in the Netherlands is exported abroad of which around one quarter illegally
Overall, between 62 and 70 kt of the total of discarded EEE was exported from the Netherlands in 2018 (Figure 2.3). As no single data set comprehensively describes these export flows, they have been constructed by combining various data sources with differing classifications (See Appendix B). Calculations were performed at the level of UNU-KEYS, and subsequently grouped into the 6 categories of the WEEE Directive (see Appendix C). In general, the classifications to measure the transboundary movement of e-waste are not fully adequate. Some data sources overlap, partly, with the risk of double counting, while for some other flows and products, there are no suitable data sources available (especially for the illegal e-waste exports). As the presented data still have some gaps on destinations, they probably represent a lower estimate of export flows.

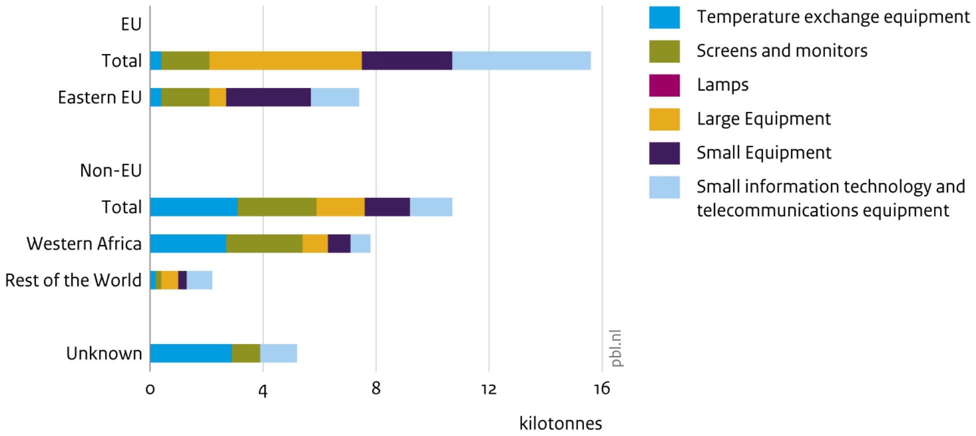
Legal e-waste export: Of the total of generated e-waste and used EEE that was collected and registered in the *Nationaal (W)EEE Register* in 2018, approximately 19 kt (10%) was exported as legal e-waste to recyclers in the EU (NWR, 2019). This concerned e-waste that was collected in the Netherlands and sent for pre-processing or final processing in another country. Those exports are regulated by the Dutch Producer Compliance Schemes, of which Wecycle is the largest.

The exports all go to WEEELabex certified recyclers, as required under Dutch law, which means that a certain level of auditing and verification is expected to take place on this flow. There was no further information on the categories or destinations of this legal e-waste, but these are probably recyclers close to the Dutch border.

Illegal e-waste export: The most recent estimate of illegal e-waste export stems from 2010 and concerned 3 to 9 kt (Huisman et al., 2012). These exports only comprised of unmixed, homogeneous, e-waste and did not include e-waste mixed in with scrap metal. The estimate might therefore be too low. At EU level, illegal e-waste exports in 2012 were estimated at 0.7 to 1.2 kg/per capita (Huisman et al., 2015). Applying these averages for the Netherlands to 2018 would amount to around 12 to 20 kt in illegal e-waste exports. This extrapolation of the EU average is assumed to be more accurate as it also covers e-waste mixed in with scrap metal and non-functioning used EEE. It is clear that more research is needed on this aspect. The destinations of the illegal exports are unknown. For e-waste mixed in with scrap metal that is exported, the destinations are probably to neighbouring countries. If the e-waste is exported mixed in with functioning items, it is expected that the destinations are similar to those of used EEE exports (see Figure 2.4).

*Export of used EEE for reuse***:** The total quantity exported for reuse in 2018 is estimated at 31 kt (Baldé and Van den Brink, 2020). This comprised all types of used EEE except for lamps and PV panels. The destinations could not be traced for all exports. Some data sources could be directly linked to the destination, such as those from trade statistics, whereas for others, such as reused IT servers and professional printers, destinations were unknown. A total of 18.3 kt could be traced to specific countries/regions (Figure 2.4; see Appendix D for detailed data). At least half of the export for reuse went to countries within the EU itself, and mostly comprised of large and small equipment and small IT. Around half of this concerned common household appliances that could be traced to Eastern Europe (mostly to the Czech Republic, Romania, Hungary and Bulgaria), but could subsequently have been re-exported to non-EU countries. At least one third of the total export could be traced to places outside the EU, mainly to Western Africa (mostly Nigeria and Ghana). The 1.82 kt of tested used EEE that could be traced from the LUCA Testing Facility in the Port in Amsterdam to Western Africa. Further analysis of the trade statistics revealed Ghana, Senegal, Gambia as destination countries. The used EEE that was hidden in second-hand vehicles mostly found its way to Nigeria (75%) and Ghana (20%), and concerned approximately 4.7 kt. Furthermore, used EEE exported to the African continent is often mixed in with broken and non-functioning items, which is actually e-waste and therefore illegal (Odeyingbo et al., 2017). Other destinations derived from trade statistics concerned countries in Western Asia (Turkey and Cyprus), Eastern Asia (Hong Kong and China) and Southeast Asia (mostly Singapore). It is uncertain if these were final destinations, catering to the poorest part of the local community, refugees and migrant workers, or transit points to other countries in the region. Other minor destinations were found to be in Northern and Eastern Africa, with less than 1 kt in exports. For 4.6 kt, the destination could not directly be derived from the data sources, but was likely to include the same countries.

Figure 2.4
Export of used electrical and electronic equipment from the Netherlands, 2018



Source: UNU/UNITAR

Western Africa expected to feel most severe impact of discarded EEE exported from the Netherlands

A first assessment of the potential impact of e-waste and used EEE exported from the Netherlands on receiving countries was made by comparing 2018 data on imported discarded electronics (Table D.1) with domestic e-waste generated in the region (Table 2.1). The impacts are likely the largest for Western Africa, as the amounts imported from the Netherlands to that region are the largest, the amount of domestic e-waste generated in Western Africa is far less than in the other regions, and only 0.4% (2 kt) is documented to be managed in an environmentally sound manner. In 2018, the used EEE and e-waste exported from the Netherlands to Western Africa approximately concerned 10 kt, which included at least 7.8 kt of used EEE and an estimated 2.3 kt of illegally exported e-waste. Illegally exported e-waste is conservatively estimated at 30% of all used EEE exports from the Netherlands to non-EU countries in 2018. As used EEE eventually also becomes e-waste, this exported amount increased that year's domestically generated e-waste in Western Africa by at least 1.5%. This additional e-waste was most likely also not managed in an environmentally sound manner.

The Netherlands is not the only country exporting used EEE and e-waste, and its related policies are closely linked to those of the EU. EU data on exports have not been updated since 2012, and those export data were not mapped to destinations. As a ballpark figure and rough estimate, we assumed that the export findings for the Netherlands (3.9% of total discarded EEE in 2018) could be extrapolated to the EU. This means that, in 2018, the EU exported around 250 kt of used EEE and illegal e-waste to Western Africa, which was around 40% of domestically generated e-waste in Western Africa. The imports of used EEE and e-waste from the EU were not included in the amount of e-waste domestically generated in Western Africa, and not all imported used EEE was documented correctly and reflected in the official consumption data. Therefore, imports of e-waste and used EEE from the EU may potentially double the amount of e-waste generated domestically in Western Africa.

Table 2.1 E-waste generated domestically (excluding imports) in selected non-EU regions, in 2018 (source: Forti et al., 2020)

	E-waste generated domestically (kg/per capita)	Total e-waste generated domestically (kt)	E-waste documented as collected and properly recycled (%)
Western Africa	1.7	650	0.4
Eastern Africa	0.8	300	1.3
Northern Africa	5.4	1300	0
Western Asia	9.6	2600	6
Eastern Asia	8.6	13700	20
Southeast Asia	5.4	3500	0

3 Impact of current trade flows

To assess socio-economic and environmental impacts of circular economy strategies in low- and middle-income countries, it is necessary to identify and describe current impacts from the transboundary trade in discarded electronic equipment. This chapter discusses the main impacts associated with the trade in e-waste and used EEE, with a focus on Nigeria and Ghana, the largest non-European recipients of these trade flows. As the focus is on the reuse and end-of-life stages of electrical and electronic products, the impacts of resource extraction, manufacturing and first-use stages of new products were outside the scope of the analysis.

3.1 Analysing impact

The impact analysis was based on a combination of literature review and expert consultation. The literature review included academic papers, reports from multi-stakeholder platforms (e.g. StEP Initiative), producer responsibility organisations (e.g. the WEEE Forum), and reports from international organisations (e.g. the World Health Organization, the International Labour Organisation). The expert consultation process was conducted through semi-structured interviews with scientists, policymakers, and representatives from NGOs, advocacy groups and the private sector (listed in Appendix A).

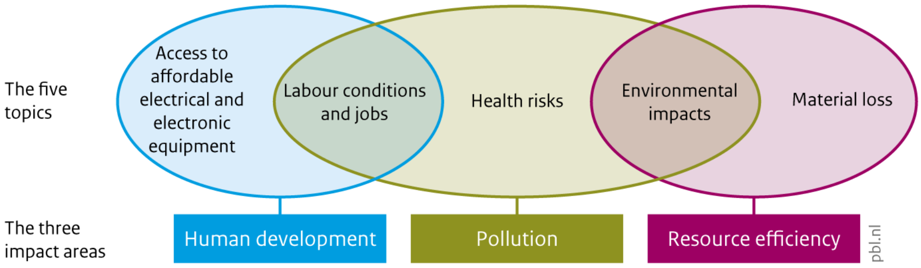
Five main topics stand out, covering most of the negative and positive impacts of e-waste and used EEE imports in low- and middle-income countries (see Table 3.1):

1. environmental damage
2. public health risks
3. labour conditions and jobs
4. access to affordable EEE
5. material losses

Some of these topics have been studied in detail, such as health risks, especially in countries where e-waste and used EEE is processed in large quantities in the informal sector, such as in India, China, Ghana and Nigeria. Other topics received less attention, such as access to affordable electronic equipment.

Circular economy practices and related business models have been presented as tools to help achieve several SDGs (Schroeder et al., 2019). At the same time, making progress on the SDGs also requires proactively addressing the e-waste challenge, which is also recognised in the Government-wide Programme for a Circular Economy (Ministry of IenM and Ministry of EZ, 2016). International trade and management of discarded electronic equipment closely relates to many SDGs, such as SDG 8 on decent work and economic growth, SDG 3 on good health and well-being, and SDGs 13–15 on climate and biodiversity. Given the large raw material demand in electronics production, e-waste also closely relates to the SDG targets on resource efficiency, decoupling and sustainable consumption and production (SDGs 8.4, 12.1 and 12.2).

Figure 3.1
Relationship between the five topics and three underlying impact areas



Source: PBL

More specifically, for e-waste, sub-indicators have been included (SDG 12.5.1) on national recycling rate, in tonnes of materials recycled, and (SDG 12.4.2) on hazardous waste generated per capita and proportion of hazardous waste treated. Linking our five topics to SDGs shows how the handling of e-waste and access to used EEE are affecting sustainable development (Table 3.1).

Looking at these topics more closely, three underlying impact areas can be identified:

1. *Pollution*: Pollution in the context of e-waste refers to the presence and release of hazardous substances and greenhouse gas emissions to air, water and/or soil, as well as concentrations of substances that are hazardous above certain thresholds. Pollution forms the underlying issue of most public health problems, many of the labour risks and almost all environmental damage. Only in the case of physical injury through trauma is pollution not a key underlying issue.

2. *Human development*: The transboundary trade in e-waste and used EEE exists in its current form because this benefits large groups of people in one way or another. Human development relates to access to affordable electrical equipment for consumers and the opportunities to make a living from working in the e-waste value chain.

3. *Resource efficiency*: resource efficiency refers to the number of products, the materials or services that can be derived from a resource unit. In relation to e-waste, this refers to how much material is recovered from e-waste, in terms of actual material recovery rates as well as their economic value. It also refers to how long materials remain in use, in the sense that for example reuse or repair is more resource-efficient than discarding, incinerating or recycling them after first use. Current practices of transboundary trade in used EEE and e-waste result in material losses for the exporting countries, as potential secondary materials leave the economy. On the other hand, recycling does not mean that all materials can be recovered, for example the recovery of most rare earth elements (REEs) faces physical, technological and economic limitations.

These three impact areas are not mutually exclusive, but are collectively exhaustive. All developments that affect these underlying issues will affect the impacts associated with these areas. Figure 3.1 shows the link between the five topics and the three impact areas. Sections 3.2–3.4 discusses the three impact areas in more detail.

Table 3.1 Main impact areas of the transboundary trade in e-waste and used EEE

Category	Brief description	Underlying drivers	Corresponding SDGs
Access to affordable EEE	Access to affordable EEE is important for development.	Used EEE from the EU is sought after, because of its high quality and durability.	SDGs 1 and 9
Labour conditions and jobs	E-waste and used EEE are a source of income, also for unskilled workers. Most work is in the informal sector, is often dangerous and done by vulnerable groups (women/children/migrants). Low wages, no social security or no access to healthcare are the norm.	E-waste and used EEE as a source of income; poverty; lack of decent jobs; lack of protection for workers.	SDG 8
Health risks	Workers and communities experience short- and long-term health problems: trauma; injury; illness; reproductive and prenatal problems; developmental impairment.	Exposure to hazardous substances; not using personal protective equipment; unsafe recycling activities.	SDG 3
Environmental damage	Soil, water and air pollution, ecosystem damage, climate change.	Hazardous substances and greenhouse gas emissions from used EEE and e-waste are released into the environment from the incinerating, dismantling or discarding of e-waste.	SDGs 6, 11, 12, 13, 14 and 15
Loss of valuable materials	Loss of materials due to exporting used EEE and e-waste, and inefficient processing in the informal sector.	Most exported materials are not returned to their countries of origin; inefficient recycling; dumping.	SDGs 8 and 12

3.2 Pollution

In most low- and middle-income countries, an adequate waste management infrastructure is either lacking or not fully developed (Edmonds et al., 2019). As a result, handling of e-waste is associated with serious pollution, affecting both human health (SDG 3) and the environment (SDGs 6, 12, 11, 13, 14 and 15).

Electronics contain many hazardous and toxic substances

The improper management of e-waste is connected to contamination and pollution of groundwater, soil and air. About 69 elements from the periodic table can be found in electronic equipment (Forti et al., 2020). Hazardous or toxic substances include, for example, heavy metals, brominated flame retardants (BFRs) chlorofluorocarbons (CFCs), and hydrochlorofluorocarbons (HCFCs). Annually, up to 0.05 kt of mercury and 71 kt of Brominated Flame Retardants (BFRs) are found in undocumented e-waste, most of which is eventually released into the environment (Forti et al., 2020).

In addition to hazardous chemicals, e-waste and used EEE contain greenhouse gases and ozone depleting substances. Greenhouse gases embedded in certain equipment, such as refrigerators and air conditioners, are released during dismantling. Gases in refrigerators, such as Freon R-12, have a strong negative impact on global warming. One kg of Freon R-12 is equivalent to 10,900 kg of CO_2 in terms of impact on global warming (Lenz et al., 2019). Over 98 Mt in CO_2 equivalents are released from the inferior recycling of refrigerators and air conditioners (e.g. chlorofluorocarbons and hydrochlorofluorocarbons). Furthermore, appliances such as refrigerators and air conditioners contain substances that not only contribute to global warming, but also damage the ozone layer in the Earth’s atmosphere. Before 1994 and up to 2017, refrigerants with a high global warming potential were used. Since then, those refrigerants have been substituted with substances that have a lower global warming potential. The full effects of this change will become visible in the next decades, as the more recent equipment becomes waste (Forti et al., 2020).

Health risks relate to both direct and indirect exposure to dangerous substances and environmental pollution.

See Appendix D, for an overview of relevant chemicals, how they are applied and their associated health risks. Direct and indirect exposure to hazardous substances is often a consequence of the techniques used by informal workers to extract valuable materials. Dangerous substances can directly affect workers handling the e-waste and contaminate the surroundings of nearby communities (Forti et al., 2020). The worst health impacts occur during processing, dismantling, material recovery (especially burning), and final disposal. The negative impacts that occur during collection, refurbishment and repair of EEE, are generally at a significantly lower level (Schluep et al., 2011).

In addition to the direct risks to human health, substances that can accumulate in the soil or sediment also pose significant risks to terrestrial and aquatic animals, in turn indirectly affecting the health of people that consume them. For example, during e-waste dismantling and recycling, large amounts of heavy metal may eventually end up in rivers. This then can accumulate in the water and sediment, and become absorbed by aquatic food chains, with toxic implications for aquatic species and/or the people that may eat them. Similar effects may occur on land, as a result of bioaccumulation in terrestrial food chains, through plants or even cattle (Kyere et al., 2018). The accumulation of hazardous substances in the soil and water is worrying in the long term, as persistent substances could also have future impacts, if e-waste sites are ever used for other activities before they are thoroughly cleaned up (Ohajinwa et al., 2019).

E-waste handling causes both short- and long-term risks for human health and the environment
Hazardous substances move from e-waste into the environment, where people are exposed through inhalation, direct dermal contact and the intake of food and water. Workers can also bring hazardous substances that are on their clothes and skin into their homes. Some of these substances are highly persistent in the environment, bio-accumulate in food chains, and carry a large potential for long-range environmental transport (Awasthi and Li, 2017; Ohajinwa et al., 2019). This means that the threat of negative public health impacts through environmental pollution is immediate, in many places where e-waste is handled, but may also extend to areas further away. For example, research in Ghana has found high levels of PCBs in blood samples of people living in Accra who had never handled e-waste themselves (Wittsiepe et al., 2015).

Some of the e-waste processing techniques also pose other types of risk. Workers dismantling e-waste come into direct contact with polychlorinated biphenyls (PCBs) and other persistent organic pollutants (POPs) in fluids, lubricants and coolants. Recovering copper frequently involves burning the plastic coating from wires, which releases harmful polyvinyl chloride, dioxins, furans, brominated flame retardants and polycyclic aromatic hydrocarbons (PAHs) into the environment (Asante et al., 2011; Wittsiepe et al., 2015). Melting down lead in open pots carries a high risk of chemical injury if workers do not have protective equipment. The harmful by-products that are released during the burning can increase the risk of respiratory and skin diseases and eye infections for people nearby (Ohajinwa et al., 2017; Ohajinwa et al., 2019)

Workers and people living in or near informal facilities are exposed to pollutants over a long period of time, either directly through contact or inhalation, or indirectly through contamination of the food and water supply (Heacock et al., 2016). Research in Nigeria shows that, at all the e-waste sites analysed, exposure to polybrominated diphenyl ethers (PBDEs) and metals via inhalation, dermal contact and ingestion exceeded the acceptable (i.e. safe) limits by several orders of magnitude, carrying the risk of both non-cancerous health effects and cancer (Ohajinwa et al., 2019). The effects on public health can also be delayed over a longer period before they become apparent (Wittsiepe et al., 2015). Many e-waste compounds are carcinogenic and prolonged exposure can lead to neuro-degenerative disease. Toxic elements from e-waste are found in the blood streams of informal workers at dumping grounds, where burning over open fires is used to harvest metals. These dumping grounds have become economic hubs, attracting food vendors, and are often adjacent to informal settlements (Ohajinwa et al., 2019).

Children and women are particularly vulnerable
Children and women who are active in the e-waste value stream are exposed to several health and safety risks (Grant et al., 2013). Adult women and girls represent up to 30% of the workforce of waste pickers, in some communities, working on dumpsites in Ghana and Nigeria. They are mainly involved in the collection and dismantling of e-waste. This includes activities such as manual stripping to remove electronic boards for resale, open fires for burning off the casing of wires to recover major components (copper, aluminium, iron), and the deposition of other bulk components, including CRTs, out in the open on dumpsites. Women and children are also exposed indirectly by being near e-waste recycling, by selling food and beverages near the work sites, or children by simply playing around such sites (Osibanjo, 2015).

The large share of women working at dismantling sites is alarming, because if they are pregnant or nursing an infant, these children also become exposed to toxic compounds and the related health risks (Kim et al., 2019). These health risks include increases in spontaneous miscarriages, still and premature births, reduced birthweights and birth lengths, high incidences of birth defects and high infant mortality (Grant et al., 2013; Guo et al., 2012; Wu et al., 2012; Xu et al., 2012; Zeng et al., 2016).

Children are commonly seen at e-waste recycling sites, more so in certain countries than in others. They are usually involved in waste collection and crude dismantling practices or in selling food and water (Heacock et al., 2016). Research from Ghana estimates that roughly 11.7% of the e-waste workers are under the age of 15 (Adanu et al., 2020). Exposure to hazardous materials such as high concentrations of heavy metals poses serious health risks for children actively participating in or living nearby e-waste recycling sites. For example, heavy metal exposure through e-waste is associated with lower body weight, higher prevalence of attention deficit hyperactivity disorder (ADHD) and higher incidence of DNA and chromosome damage (Zeng et al., 2016).

Research in China also found that the immune responsiveness to routine vaccination was suppressed in children chronically exposed to lead. This in turn may lead to an increase in infectious diseases among the population, thereby constituting an additional public health problem (Lin et al., 2016). Aside from immune system impacts, exposure to heavy metals for children results in both acute and chronic effects, ranging from minor upper respiratory irritation to chronic respiratory, cardiovascular, nervous, urinary and reproductive diseases, as well as aggravation of pre-existing conditions and illness (Zeng et al., 2016). Furthermore, exposure to high levels of chromium, copper, mercury and lead around burning and dismantling areas has been found to carry significant risks of developmental and neurological disorders in children (Kyere et al., 2018).

Box 3.1: Vulnerability of children to e-waste-related health impacts (*Zeng et al.*, 2016)

Compared to adults, children are considered more vulnerable to the health risks of hazardous substances in e-waste, for several reasons:

- more routes of exposure (breastfeeding, placental exposures, hand-to-mouth, object-to-mouth);
- higher basal metabolic rate, and higher comparative uptakes of food, lower toxin elimination rates;
- higher ventilation level per minute in relation to body size, children can inhale more harmful substances;
- much larger surface area in relation to body weight, their body can load larger amounts of toxicants through dermal absorption;
- organs or tissues are still developing and more sensitive to disturbed cellular processes;
- children have more physical interaction with their environment, they are likely to receive bigger doses of toxicants, relative to their size.

3.3 Human development

Despite the serious negative impacts on human health and the environment, the influx of used EEE and e-waste into low- and middle-income countries also positively impacts human development. Used EEE is a source of affordable electrical and electronic equipment, improving people's standard of living (SDG 1) and increase access to Information and Communication Technologies (SDG 9), while repair and waste collection, sorting and recycling provide jobs and incomes for a large group of people (SDG 8).

Imported used EEE is an important source of affordable electronic equipment for consumers in Ghana and Nigeria

The widespread availability of EEE and ICT has helped to achieve a higher standard of living for people around the globe (Umair et al., 2015). For example, refrigerators and freezers enable long-term food storage and communication technology allows for the rapid exchange of information and advances education. For this reason, ICT access has specifically been identified as an indicator of a country's economic and social development (Asongu and Le Roux, 2017). There is a difference in ICT access between high-income countries and low- and middle-income countries, also known as the 'digital divide'. While there are many factors that contribute to this digital divide, the relatively high price of ICT hardware has been found to be significant (Asongu and Le Roux, 2017; Nnorom and Odeyingbo, 2020).

Nevertheless, in recent years, Africa has been undergoing a rapid ICT transformation, with imported used EEE attempting to bridge this divide (Schluep et al., 2011). Countries such as Nigeria and Ghana have a growing middle class but also relatively high poverty rates. The import of second-hand EEE from other regions provides affordable access to such equipment. The relatively high product standards in the EU mean that second-hand equipment from Europe is more sought after than products from regions with lower standards, as they last longer and can be repaired more easily (Nnorom and Odeyingbo, 2020; Odeyingbo et al., 2017).

Another reason why used EEE is preferred over new appliances, is that in some countries the public power grid can be unstable, with frequent power cuts. This damages the appliances and can even destroy them. In combination with limited purchasing power, this drives a demand for cheap used EEE. This also attracts imports of used EEE with a higher reuse value in for example Nigeria than the recycling value in Europe (Nnorom and Odeyingbo, 2020). When combined with the high level of skill in the repair and refurbishment industry, along with reasonable service costs in the countries importing used EEE, traders are motivated to import both functioning and non-functioning equipment (Edmonds et al., 2019; Odeyingbo et al., 2017). Not only are labour costs much lower in Western Africa than in Europe, spare parts from non-functioning used EEE are also readily available and cheap. These factors make it very attractive for consumers in countries such as Nigeria to choose used EEE over new EEE, in contrast to consumers in for example Germany or the Netherlands (Edmonds et al., 2019; Odeyingbo et al., 2017).

Waste collection, repair, sorting and recycling provide jobs and income

E-waste and used EEE create jobs and contribute to a large repair and recycling industry in the cities where e-waste processing takes place (Oteng-Ababio and Grant, 2020). The exact number of people working in the e-waste sector is not known and is difficult to determine (McMahon et al., 2020). The International Labour Organization (ILO) has estimated that, since 2013, 19 to 24 million people around the world have been depending on solid waste management and recycling for their livelihood (Edmonds et al., 2019). Most of these workers are not officially employed but work in the informal sector. In 2013, only around 4 million people were formally employed in this industry (Edmonds et al., 2019).

The ILO estimates that, in Nigeria, in 2019, up to 100,000 people were working in the informal e-waste sector (Goel, 2019). For Ghana, research from 2010 estimated that between 20,300 and 33,600 people were employed in the collection, recycling and refurbishing of e-waste in Ghana, at the time. And, also in that year, as many as 57,600 additional people were dependent on collection and recycling activities, with an estimated 144,000 people dependent on refurbishment activities. The report also found that, in total, in terms of dependence on informal refurbishing and e-waste recycling, between 121,800 and 201,600 people in Ghana were dependent on this sector, representing between about 1.04% to 1.72% of the total urban population in Ghana, or 0.50% to 0.82% of the total Ghanaian population in 2010 (McMahon et al., 2020; Prakash et al., 2010).

The monthly income of waste collectors in Ghana, in 2010, ranged between USD 70 and 140, for refurbishment workers between USD 190 and 250, and for recyclers between USD 175 and 285. Expert opinion suggests that these incomes could have been lower, in case the regular supply or collection of e-waste would have been hampered. If the partial or full dependency of family members of these workers in included, most of these workers could be concluded to live below nationally and internationally defined poverty lines (Prakash et al., 2010; Amoyaw-Osei et al., 2011).

According to a research survey conducted in Lagos in 2013, collectors and recyclers in the informal sector indicated they had no intention of changing their jobs, due to the income they were able to generate from e-waste. Respondents also mentioned that, while the informal business was thriving, the lack of alternative means of income was also a factor in them continuing their work as collectors and recyclers. In the survey, the people working in the informal sector indicated that they did not consider the legal minimum wage level high enough to start looking for employment in the formal sector. It should be noted that informal workers, for example in waste collection, are also organised and often form cooperatives or similar enterprises. Through networks of collectors, recyclers and the repair industry, workers from the informal and formal e-waste value chain co-exist and cooperate (Edmonds et al., 2019).

Different types of jobs carry different risks and benefits

The e-waste value chain is highly complex and differs between countries and regions (Edmonds et al., 2019). The circumstances and characteristics of people working in e-waste collection, dismantling and repair also vary per type of job. In Nigeria, used EEE and e-waste repair recycling work is usually done by men. In the Lagos region, the e-waste workers are often migrants looking for a temporary means to make a living, although many end up staying for years. In other parts of Nigeria, fewer migrants are active in the industry, and working with e-waste is done by people from various generations. In Ghana, many e-waste workers originally were migrants from the North, who came to look for work in Accra (Osibanjo, 2015; Oteng-Ababio and Grant, 2020). Both Ghana and Nigeria have a highly organised repair and refurbishing industry, focusing on imported used EEE as well as domestic sources of e-waste and used EEE.

The International Labour Organisation (ILO) has published an overview of a 'typical' e-waste value chain, based on the situation in Nigeria, Argentina and India, in 2019, which shows the similarities in how the work is structured and organised around the world (see Figure 3.2; (Edmonds et al., 2019). Workers have different levels of education and income and are active in varying types of working environments. Below, we discuss the main groups of e-waste workers, in more detail, active in waste collection, dismantling and recycling, and refurbishment and repair.

Box 3.2: Informal employment

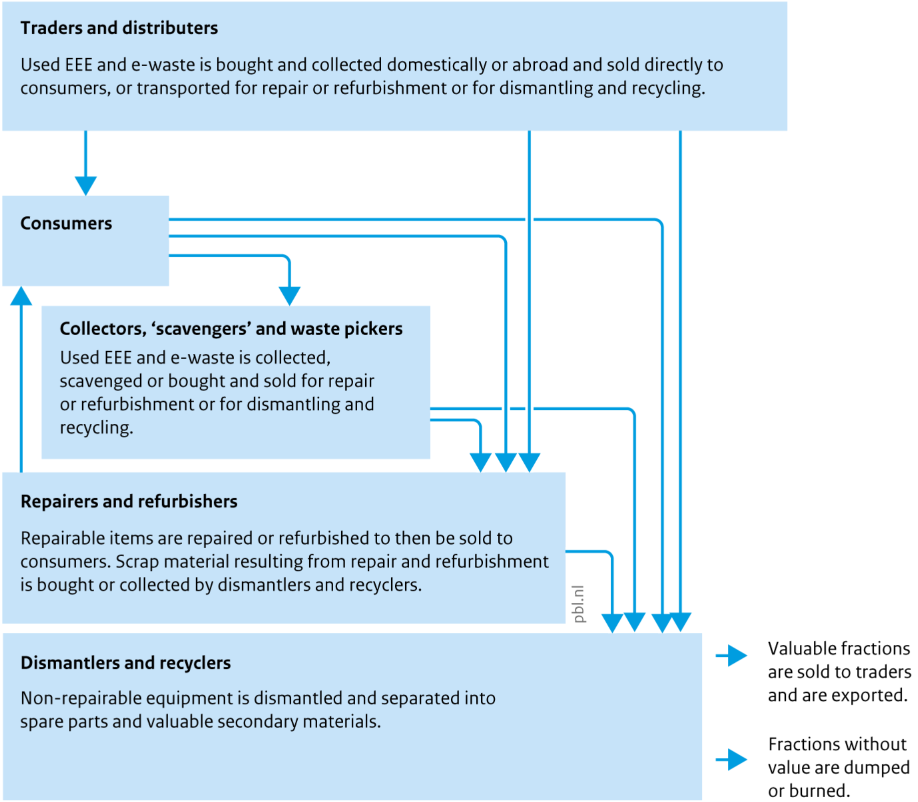
Informal labour is defined as an employment relationship that, under the law or in practice, is not subject to national labour laws, income tax, social protection or entitlement to certain employment benefits (e.g. advance notice of dismissal, severance pay, paid annual leave or sick leave). The majority of workers in low- and middle-income countries consists of informal workers; most of them are also self-employed. In 2016, at least 6 out of every 10 workers, globally, were working in the informal economy. In several countries, this number is increasing. There is significant link between informal employment and poverty, with informal workers facing severe decent work deficits. Everywhere and at all levels, globally and regionally, there is a clear link between increases in the level of education of workers and decreases in the share of informal employment. Informal work usually arises in the absence of other means of earning a living and forms a major challenge to achieve decent work for all (Bonnet et al., 2019).

Collectors, 'scavengers' or waste pickers operate in an effective informal network
In Nigeria and Ghana, the collection of e-waste is generally an informal economic activity. Collectors and waste pickers are sometimes also referred to as *scavengers*. As collectors and waste pickers collect different types of recyclable waste simultaneously, it is difficult to determine to what extent people work with e-waste specifically (Goel, 2019). In Nigeria, it is estimated that, in 2010, approximately 80,000 to 100,000 people were engaged in the collection of recyclable waste, including e-waste and scrap metal, with 80% of these workers operating in the informal sector and 20% in the formal sector (Goel, 2019; Osibanjo, 2015). Research showed that, in 2009, approximately 30% of waste pickers on dump sites in Nigeria were female (Manhart et al., 2011). In Ghana, e-waste is also collected by children (mostly boys) and women (Osibanjo, 2015).

The amount of e-waste that is being collected varies greatly, with researched published in 2012 showing that, at that time, collectors in Nigeria had collected between 144 and 1,985 kilograms of e-waste mixed in with scrap metal, per week. Experienced collectors are skilled at distinguishing valuable from worthless items. While formal collectors use large vehicles to transport e-waste, informal collectors use simpler modes of transportation, such as handcarts. According to a country assessment by Ogungbuyi et al. (2012), between 60% and 83% of e-waste collected in 2010 was bought directly from households and businesses, while 17% to 40% was picked up for free at dumpsites, landfills or from the streets. Collectors and waste pickers typically sell the collected e-waste to refurbishers, scrap metal dealers or recyclers (Goel, 2019; Ogungbuyi et al., 2012). Research in Nigeria shows that collectors who can afford to buy scrap metal tend to generate a larger income than collectors and waste pickers who rely on free waste, as the former group has access to higher quality and more valuable used EEE (Edmonds et al., 2019).

Repairers and refurbishers have higher incomes and their work is more formalised
Refurbishers and repair technicians, generally, earn more and are better educated than other workers in the e-waste value chain. This type of work is also more or less formalised, with many workers paying taxes and registering with relevant authorities. On top of that, the occupational health and safety risks associated with refurbishment are estimated to be lower than in recycling or dismantling but still involve exposure to hazardous substances (Goel, 2019; Ohajinwa et al., 2019). Refurbishers in Nigeria are generally members of refurbishers' organisations, such as the Nigeria Association of Refrigerator and Air Conditioner Practitioners (NARAP) and the National Electronics Technicians Association of Nigeria (NETAN). Refurbishers in Nigeria are organised based on the types of EEE they repair; for example, refurbishers of refrigerators will normally not repair laptops (Goel, 2019).

Figure 3.2
The e-waste value chain in low- and middle-income countries



Source: PBL

New and used EEE that cannot be refurbished or repaired ends up as e-waste. In Nigeria, research found that, in 2010, roughly 66% to 68% of electronic equipment brought to refurbishing workshops was functioning. Around 12% to 25% of refurbishers disposed of e-waste along with regular waste, while 66% sold e-waste to collectors (Goel, 2019; Ogungbuyi et al., 2012).

Within the group of refurbishers, there are differences in levels of income, with the owners of refurbishing workshops earning the most, followed by employees and then apprentices. Apprentices typically receive a small amount of money to pay for food and transport. After four to five years of work, apprentices often start their own workshop (Edmonds et al., 2019).

Recyclers face the highest risks and operate in the informal sector
Recyclers dismantle appliances, separate components and recover metals from e-waste. This can be done by individuals or by organisations. Dismantled and separated parts are sold as secondary materials to traders and suppliers in the manufacturing industry. Recyclers are primarily interested in aluminium, copper and steel. A lot of material has no economic value and is discarded, thus informal recyclers also generate a large amount of waste, which is often disposed of improperly. Most recyclers work in the informal sector. There are only very few registered recycling facilities in countries such as Nigeria (Edmonds et al., 2019; Goel, 2019; Nnorom and Odeyingbo, 2020). The sites where materials are incinerated in open fires carry the highest level of health risks for e-waste workers, associated with exposure to PBDEs and metals (Ohajinwa et al., 2019).

Research in Nigeria shows that the majority of workers also do not wear personal protective equipment. Without protective equipment, workers are more exposed to hazardous substances, as their limbs and faces are usually mostly uncovered. Workers often find protective equipment uncomfortable and do not want to spend money on it. Furthermore, most e-waste workers have low education levels and have insufficient knowledge of the health risks of not using protective equipment. Studies find a positive correlation between knowledge of health risks and the use of protective equipment. This could indicate that increasing awareness could lead to more widespread use of protective equipment (Ohajinwa et al., 2017; Ohajinwa et al., 2019).

There are very few registered e-waste recycling facilities in Western Africa that provide environmentally sound recycling. In 2018, the Government of Nigeria approved the first formal e-waste recycling facility in the country, located in Lagos and run by Hinkley Recycling (Goel, 2019). In Ghana, research up to 2019 showed there to be no formal, registered e-waste recycling facility technically capable of safely processing e-waste (Keesman, 2019).

3.4 Resource efficiency

Electrical and electronic equipment (EEE) contains many different valuable materials. When exporting used EEE and e-waste, these materials are lost for the European economy. Certain valuable materials are recovered in Western Africa, in the informal sector, other materials are discarded (SDGs 8 and 12).

Metals and minerals found in e-waste are important for the European economy
Critical raw materials are highly important for the EU economy and the risk associated with their supply certainty is high. Materials listed as critical by the European Commission include cobalt, palladium, indium, germanium, bismuth, and antimony (European Commision, 2017; Forti et al., 2020). These rare earth metals, for example, are essential not only for renewable energy technologies, such as wind turbines, electric cars and solar panels, but also for telecommunication and medical and defence technologies. China is a dominant player on the global market of rare earth metals. Nearly 40% of the world’s reserves are located in China and China produces around 95% of the global supply (Statista, 2020; United States Geological Survey, 2020). This market dominance causes great concern about reliable, sustainable and legitimate access to these critical metals. For example, for the energy transition, there is a risk of shortages of the materials needed to generate renewable energy on a large scale (Bosch et al., 2019; Işıldar et al., 2018; van Exter et al., 2018).

Rate of reuse, repair and collection of used EEE and e-waste is high in Western Africa
In countries such as Ghana or Nigeria, used EEE and e-waste collection rates in the informal sector are quite high. Precise data are scarce, but estimates of up to 95% are reported for Ghana, for 2011 (Manhart et al., 2020; Nnorom and Odeyingbo, 2020; Schluep et al., 2011). For the EU in 2019, this was estimated at 52% (Baldé et al., 2020b). Significant amounts, on average 1.4 kg per EU inhabitant, of used EEE or e-waste were disposed of in municipal solid waste streams, with materials not being recovered (Baldé et al., 2020b). This amounted to roughly 8% or 0.6 Mt of e-waste having ended up in waste containers in 2019 (Forti et al., 2020). Another leakage stream is e-waste mixed in with scrap metal, estimated for 2018 at an average 2.1 kg per EU inhabitant, from which bulk metals are recycled, but precious metals and other materials are not reclaimed. The largest inefficiency in the Netherlands, however, is related to 25% of the e-waste flows that cannot be traced (Baldé et al., 2020b). In Europe, since 2012, e-waste is being collected in six different categories with a wide variety of products. For this reason, manual sorting and dismantling is usually more effective than automated processes. In this way, a better category purity or even product purity can be guaranteed, making the final recycling more efficient and supporting the creation of value from e-waste (Edmonds et al., 2019). Although innovations such as the Daisy robot by Apple could largely improve dismantling, requiring less manual labour, automation still has a long way to go (Reuters, 2020).

Increasing recycling can contribute to lower demand for raw materials
Increasing recycling, substitution and resource efficiency could be used to tackle scarcity and supply risks by providing an alternative to primary production. This is not only strategic but can also be more sustainable. According to the 2020 Global E-waste monitor, a raw material value of USD 10 billion is recovered in an environmentally sound way from e-waste globally (given the 17.4% collection rate), and 4 Mt of raw materials could be made available for recycling (Forti et al., 2020). The metal content of e-waste is often much higher than in mined ores. For example, a printed circuit board typically has 10 to 100 times higher metal content than is found in conventionally mined ores (Rao et al., 2020). Furthermore, the recycling of iron, aluminium and copper, in 2019, contributed to a net saving of 15 Mt of CO_2, equivalent to emissions from the recycling of secondary materials as a substitute for raw materials (Forti et al., 2020). Improving efficiency and reducing material loss in recycling can reduce demand for primary raw materials and save energy and related greenhouse gas emissions (Reuter et al., 2013). Mining, concentrating, smelting and refining, especially of metals and rare earth elements, are very energy-intensive processes. As most electricity is still generated using fossil fuels, these processes produce large amounts of carbon dioxide emissions that contribute to climate change. Recovering some of the base metals contained in e-waste requires only a fraction of this energy input (Schluep et al., 2011). For example, up to 85% of energy use could be saved if copper would be recycled, and for aluminium the saving could even amount to as much as around 95% (Işıldar et al., 2018).

Recovery of critical materials from e-waste remains challenging everywhere
In Europe, most base metals found in e-waste, such as ferrous metals, aluminium and copper, are recycled. However, this is not the case for rare earth elements. Low market prices and technological challenges have limited recycling developments for these materials (Baxter et al., 2016; Thiébaud et al., 2018). Furthermore, given the low concentrations of rare earth elements in electronics and the increasing complexity of electronic equipment, there are no or very few options to recover them in an economically viable way (Batinic et al., 2018; Işıldar et al., 2018). The recovery of a small amount of only one type of metal out of maybe 50 other elements is already challenging, and the process can make it impossible to recover the rest.

In addition, certain elements, such as copper and iron, are very difficult to separate once they are combined (Reuter et al., 2013). Compliant recycling and recovery usually involve a substantial number of manual labour hours for pre-treatment and is also associated with higher costs. due to, for example, compliance standards, certification, reporting and equipment. Non-selective recyclers do not have these additional costs, but also have low recovery rates of precious metals (McMahon et al., 2020).

Biggest challenges for the informal e-waste sector are to improve safety and limit pollution

Data on the recovery rates of materials from e-waste in Western Africa are scarce, making it difficult to compare how much is actually recovered in relation to recovery rates in Europe. Nevertheless, research indicates that informal e-waste recyclers do recover substantial amounts of materials that are relatively easy to extract. Moreover, the recovery rates or the success of recycling greatly depend on the collection and pre-sorting of waste, in addition to the recycling process itself. Product designs or the physical properties of materials in e-waste are a third important factor in resource efficiency (Batinic et al., 2018; Reuter et al., 2013). While informal recycling cannot recover the same level of materials from e-waste, compared to professional recyclers or smelters such as Umicore, they do have access to substantial amounts of waste and are effective in terms of identifying valuable fractions, sorting, dismantling and other steps in pre-treatment. Manual pre-treatment can contribute to higher purity degrees of recovered materials (Buchert et al., 2016). Nevertheless, increasing efficiency is not the biggest challenge for the informal sector in Western Africa; the main challenges concern decent work, health and safety and preventing environmental damage.

4 Impacts of circular economy strategies

Analysing the effects of circular economy policies on low- and middle-income countries is not straightforward, given the broad range of such policies. This chapter discusses the effects on the three impact areas as presented in Chapter 3, focusing on three broad circularity strategies. The analysis concerns the direct effects of these strategies, as well as effects when including Western Africa in the circular economy loops of the Netherlands and the EU. Furthermore, the pros and cons of different routes are discussed and the issues requiring further attention are highlighted.

4.1 Structuring circular economy policies

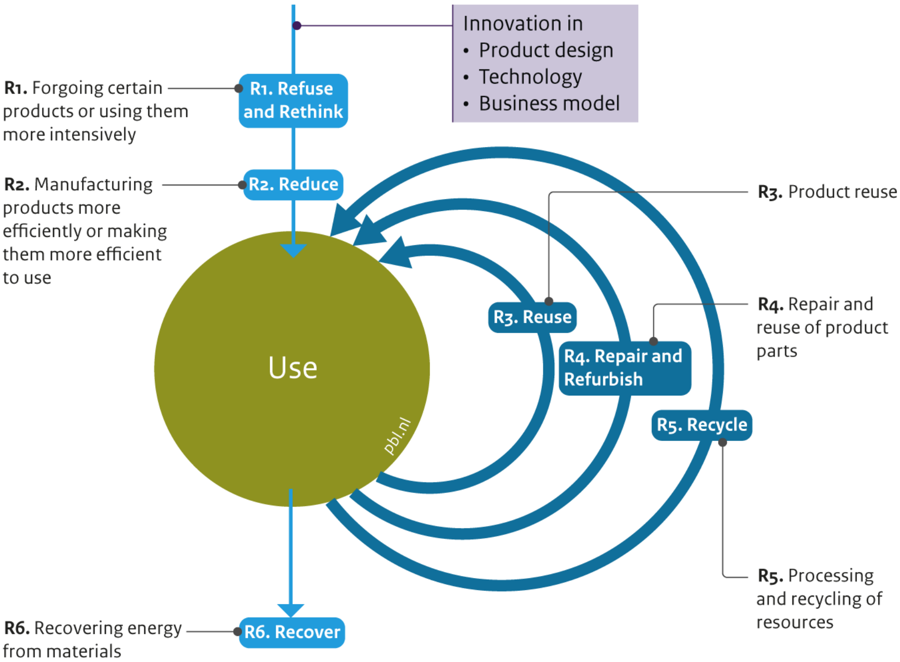
In contrast to what happens in a linear economy, a circular economy makes optimal use of resources and minimises the creation of waste. This means that products are designed to be as efficient as possible, while considering the entire lifecycle, and that the materials used to make them continue to be applied in a way that generates the highest economic value and the least environmental damage.

The conversion of a linear economy into one that is circular involves a system change, or transition, to a different way of thinking about material use. Where possible, material input is reduced or substituted with more environmentally friendly alternatives. Different approaches to consuming products are applied, alongside new business models to suit this change. Furthermore, new approaches for design and production processes are introduced, aimed at making products that last longer and can be repaired or refurbished more easily. When something does finally become waste, recycling materials and recovering as much material or energy as possible are the last options, providing secondary materials and energy inputs for new production processes.

Circular economy actions and policies can be organised along the so-called R-ladder (Figure 4.1). Not all policies are in line with one of the R-ladder rankings, as some can be relevant for several stages in the material or product value chains. For example, circular design is such a cross-cutting strategy, relevant for reducing material input (reduce), but also for extending the use phase of products (reuse, repair) as well as facilitating easier recycling (recycle, recover) (Prins and Rood, 2020).

For this study, we used a more simplified approach to labelling circular economy policy strategies, and to analyse their effects on the transboundary flow of second-hand electronics and e-waste. As several types of policies have similar effects on how resources are used, the levels on the R-ladder were clustered in measures aimed at reducing the amount of material input (narrowing loops), keeping products or materials in use longer (slowing loops), and recovering energy or recycling materials into new products and preventing losses (closing loops) (Table 4.1).

Figure 4.1
R-ladder of circularity strategies



Source: PBL

In the case of used EEE and e-waste, the following division can be made, based on type of strategy as well as the stage of the value chain:

- Strategies under *narrowing loops* refer to reduce, rethink and refuse, and should result in less overall material use. They have consequences for how many new electrical and electronic products are produced, how new electronics are made and what they consist of. *Narrowing loops* strategies do not directly affect trade volumes of e-waste and used EEE, as they mainly target new products entering the market. However, over time, these types of circular economy strategies can affect trade flows, for example through increased sharing of products or other ways to decrease consumer demand and ownership.
- Strategies under *slowing loops* include reusing products, repairing broken items or refurbishing products so they can have a second (or third, etc.) life. These strategies extend the lifetime of products and/or how long they are kept in use by consumers in Europe. This in turn could lead to a lower demand for new EEE, while reducing the availability of used EEE that could be traded abroad.
- Strategies under *closing loops* include recycling and recovery of useful fractions, secondary materials or energy of end-of-life products, labelled as e-waste. These strategies are about optimal material use and reduce the availability of e-waste that could be transported abroad.

Circular economy strategies have both direct effects (e.g. trade) and indirect effects (e.g. impacts on pollution abroad).

Table 4.1 R-ladder clustered in three strategies

CE strategy	R-ladder ranking	Examples of types of measures	Impact on
Narrowing loops	R1. Refuse and rethink R2. Reduce	Reducing material use through the sharing of products, using alternative materials or forgoing certain products	New electronics
Slowing loops	R3. Reuse R4. Repair and Refurbish	Extending use phase and lifespan of products through e.g. repair or refurbishment, repair cafes, lowering VAT on repairs, buying second hand	Used EEE
Closing loops	R5. Recycle R6. Recover	Recycling product parts and recovering materials and energy for reuse	E-Waste

These effects vary, depending on the value chain and stage of the value chain analysed. In our analysis, direct effects relate to changes in the composition and volumes of e-waste and used EEE that is generated and exported. Indirect effects are impacts on human development, pollution and resource efficiency, resulting from the changing trade flows.

All three circular economy strategies can reduce the number of discarded products available for export. Policies aimed at *narrowing loops* and *slowing loops,* generally, reduce the availability of used EEE for export, as products are kept in use longer or are not bought at all. Furthermore, when products are used longer, they might be less suitable for further lifetime extension abroad. As exports of used EEE to Africa are on average mixed in with broken and non-functioning items (e-waste), reduced export of used EEE can also reduce illegal e-waste export. Policies aimed at *closing loops* are aimed at increased e-waste handling in the EU and could reduce the transboundary movement of e-waste.

Strategies under *narrowing loops* affect new electronics entering the Dutch market and have therefore a more long-term effect on trade flows. In the short term, the largest effect of CE policies in the Netherlands on low- and middle-income countries can thus be expected from strategies under *slowing loops* (affecting used EEE) and *closing loops* (affecting e-waste).

4.2 Impact of circular economy strategies that do not include Western Africa

With respect to CE policies and international trade, the extent to which low- and middle-income countries are part of the circular economy loop is relevant; for example, through refurbishment or recycling for European consumers and producers. Section 4.2.1 discusses the potential effects of the selected Dutch CE strategies on low- and middle-income countries that are outside the EU and not explicitly included in the Dutch circular economy transition. We briefly discuss potential effects per impact area, i.e. human development, pollution and resource efficiency (see Chapter 3). Section 4.2.2 further contextualises these effects in terms of challenges and other relevant issues. The effects of the three CE strategies are discussed in reverse order of their ranking on the R-ladder, from closing loops, to slowing loops and finally to narrowing loops. Section 0 discusses Dutch CE strategies that do include Western Africa.

4.2.1 Policies and impacts of the three CE strategies

Policies that focus on increased efforts to keep and process e-waste in Europe
In this policy approach, as much e-waste as possible is processed within Europe to recover useful fractions, secondary materials and energy (*closing loops*). This includes further prevention of illegal e-waste trade from the Netherlands to countries outside the EU.

Possible policy measures: this could include stronger enforcement of existing regulation to improve reporting and monitoring, along with extra efforts to increase collection rates through official channels and stricter checks on the export of second-hand equipment. This approach will likely result in higher collection rates in the Netherlands, and in reduced illegal export of e-waste to Western Africa.

Potential effects per impact area:

- Human development: decreasing volumes of illegally traded e-waste to Western Africa will mostly affect jobs related to waste management, such as collection, dismantling and recycling or recovering valuable components. As the policies target e-waste, they do not directly affect the volume of affordable electronics available to consumers.
- Pollution: lower e-waste exports result in less hazardous waste from the Netherlands arriving in Western Africa. This could lead to less pollution, which is positive for the health of local communities and at the same time have a positive impact on environmental damage.
- Resource efficiency: lower exports of e-waste to Ghana and Nigeria, in combination with increased compliant processing of e-waste in the EU would be more resource-efficient in terms of energy and material recovery for the Netherlands.

Policies that focus on lifetime extension of used EEE in Europe
In this policy approach, as many as possible second-hand electronics are reused, repaired and refurbished within Europe (*slowing loops*). This includes efforts to limit the trade in functioning used EEE between the Netherlands and countries outside the EU.

Possible policy measures: Policies include further facilitating repair and refurbishment in Europe or the Netherlands, as well as making it easier to collect unwanted items from consumers through the proper channels. To limit the export of functioning equipment, rules and legislation on what can be exported could be adapted. As with e-waste, stronger enforcement of regulation, along with improved reporting and monitoring would be required. If successful, this approach results in higher collection rates of used EEE in the Netherlands, keeping materials in the Dutch circular economy, and thus in reduced export of used EEE to Western Africa.

Potential effects per impact area:

- Human development: limiting the trade in used EEE from the Netherlands to Western Africa can negatively affect jobs in collection, repair, refurbishment and dismantling/recycling, as less material will be available. It could also lower the volume of affordable and high-quality second-hand electronics available to consumers in the region.
- Pollution: along with shipments in second-hand appliances, there is generally a share of non-functioning items being exported, or items break on the way or shortly after arriving. Furthermore, all used EEE eventually becomes e-waste, thus the trade in used EEE also adds to e-waste generation in Western Africa. For this reason, if less used EEE is transported to Western Africa, this should result in less pollution caused by products from the EU. Ultimately, less e-waste results in less environmental damage as well as lower health risks for people.

- Resource efficiency: impacts concerning resource efficiency depend on the perspective taken. For example, if less used EEE is exported, more secondary materials could become available for the European economy and less waste will be dumped. However, in Ghana and Nigeria, there is a significantly more developed repair culture and for some materials waste management is more efficient (e.g. higher collection rates, longer lifetime extension). Extending the use phase of used EEE in Western Africa may be more resource-efficient in terms of material use than recycling functioning discarded items in the EU that could still be used or easily repaired.

Policies that focus on rethinking and reducing electronics consumption
Strategies aimed at *narrowing loops* are related to different ways of thinking about ownership and consumption of products. This can have consequences for the number of new electrical and electronic products produced, as well as for how these products are consumed or used.

<u>Possible policy measures:</u> to reduce and rethink electronic consumption, policies could focus on raising consumer awareness of the negative impacts of the production and end-of-life processing of electronic appliances. This could lower the demand for such items. Policies could also strive to facilitate new business models or initiatives, aimed at encouraging sharing and decreasing individual ownership. In the long run, lower demand for electronics in the Netherlands could mean that less used EEE becomes available and is shipped abroad.

<u>Potential effects per impact area:</u>

- Human development: if the trade flows of second-hand electronics decrease, this could have a negative impact on jobs in the electronics repair and refurbishment industry in Ghana and Nigeria. It could also lead to a reduced availability of high quality, affordable second-hand products for consumers in the region.
- Pollution: lower demand for electronics could have a positive impact on the amount of used EEE and e-waste that is generated, shipped abroad and dumped or processed under unsafe conditions. This is positive in terms of pollution and decreases the associated negative impacts on the environment and threat to public health caused by products from the EU.
- Resource efficiency: reductions in the number of electronics that are owned individually, and eventually discarded, could lead to higher resource efficiency. If lower demand leads to lower production, fewer materials would be needed and less material will eventually be lost.

4.2.2 Contextualising impacts: challenges and complicating factors
The potential effects described in Section 4.2.1 present a simplified reality, which does not consider new challenges and dilemmas that may occur as a result of, or in tandem with, the chosen circular economy strategy. We identify four issues that deserve attention when weighing the benefits and drawbacks of policies for the main impact areas.

The exports of used EEE from the Netherlands contribute to human development in Western Africa
It is relevant to emphasise the significant role of imported used EEE in Ghana and Nigeria, which is also the main driver of the transboundary trade in used EEE and e-waste. As discussed in Section 4.2.1, lower imports of used EEE can have negative effects on human development. It reduces availability and access to affordable and high-quality used EEE for local consumers, including mobile phones, household appliances and laptop computers. Furthermore, reduced influx of used EEE affects jobs in the repair and refurbishment industry, and, as these products eventually would end up as waste, also in waste processing.

While workers in waste processing usually earn less than workers in repair and refurbishment, and their work is considered more dangerous, these jobs are still an important source of income for a large group of people who may not have an alternative (Edmonds et al., 2019).

It is unclear whether there is potential for substantial decent work opportunities in e-waste management

Robust research on employment opportunities in formal e-waste management is scarce and difficult to compare. Comparison is challenging due to differing variables of scope such as economic, societal and regulatory environments, as well as timeframes and branches of the waste treatment process. However, recent research conducted in Ireland estimates that compliant e-waste processing could create roughly 50 full-time jobs in e-waste pre-processing per 47 kt of collected e-waste (McMahon et al., 2020). This number excludes jobs and labour hours in collection, administration, refurbishment, or specific waste streams collected under separate schemes, such as IT equipment.

While this calculation cannot simply be applied to the Western African context, in theory, it would mean that environmentally sound e-waste management could create one job per kilotonne of e-waste. For the total e-waste generated in 2018 in the Netherlands, roughly 400 jobs in waste pre-treatment would hypothetically be possible.

Even though it is difficult to estimate how much potential there is for decent work in the e-waste and used EEE value chains, many people currently depend on this sector for their livelihoods. In addition, circularity to a large extent already exists in Western Africa, where reuse and repair are mainstream practices, although under poor working conditions. It will be very valuable to gain more insight into the potential of formalised, decent work opportunities in e-waste treatment. In the meantime, the biggest challenges will be to make the activities in e-waste and used EEE processing safer, greener and fairer (Edmonds et al., 2019; Goel, 2019; McMahon et al., 2020).

Lower pollution levels and higher resource efficiency rates could be negated by rebound effects

Reduced availability of second-hand 'high-quality' electronics, produced in accordance with regulation for the EU internal market, can increase the demand for products from other regions. Given the importance of access to electronics for consumers in Ghana and Nigeria, it is unlikely that trade in these items will simply stop. If the EU is no longer a source of affordable used EEE for consumers in Western Africa, the EU imports could be replaced by products from other markets, such as China, where product standards are different to those of the EU. Such products may break faster and/or be more difficult to repair (Circle Economy, 2020). Moreover, with the extra strain on used EEE from unstable electrical grids, appliances are reported to break rather quickly and need repair sooner than in regions with a more stable grid. Instead of reduced pollution and increased resource efficiency, this could even result in higher levels of consumption of electronic goods, and a subsequent increase in pollution and lower resource efficiency in Western Africa. This rebound effect may limit or even completely counter the positive effects on pollution of decreased flows of both e-waste and used EEE from the Netherlands, resulting from various circular economy strategies.

Additional policies can alter the composition of traded used EEE and e-waste in the long term, making them easier and less polluting to process

Strategies that target behavioural change, lifetime extension for electronic products through repair and reuse, and environmentally sound management of e-waste, can be strengthened by more fundamental and cross-cutting changes. This includes changes in the design of electronics to make recycling or repair easier and less harmful to the environment and human health.

Where possible, new products could be designed with resource efficiency, recycling and repair already in mind, for example by avoiding combinations of materials that are very difficult to separate (Reuter et al., 2013).

Different strategies can have diverging implications for trade flows. Policies aimed at more efficient or less polluting production processes reduce the amounts and types of materials used and therefore alter the composition of used EEE and e-waste that is exported. Dependent on the focus of the redesign, this approach can make products more modular (and thus easier to process and reuse components), less resource-intensive (and thus potentially easier to recover specific materials) and less toxic (and thus less harmful for people and the environment when processed). However, design as such does not necessarily increase or decrease trade flows. This would happen when redesign is combined with strategies that are aimed at stimulating lower demand for specific electronic products or rethinking the way products are used (e.g. sharing or multifunctional products).

4.3 Impact of circular economy strategies that do include Western Africa

As discussed in Section 4.2, CE policies under current practices that do not aim to include Western Africa in the circular economy loops of the Netherlands or the EU, can directly or indirectly have a negative impact on all three impact areas. This section discusses the effects of CE strategies that do include Western Africa in the circular economy loops of the Netherlands in different ways. Four scenarios are distinguished (Figure 4.2):

A. Refurbishment of used EEE in Western Africa for European consumers.

B. Increased export of used EEE to Western Africa for value retention.

C. Export of e-waste to Western Africa for safe processing for the European market.

D. Reimportation of e-waste from Western Africa for safe processing in the EU.

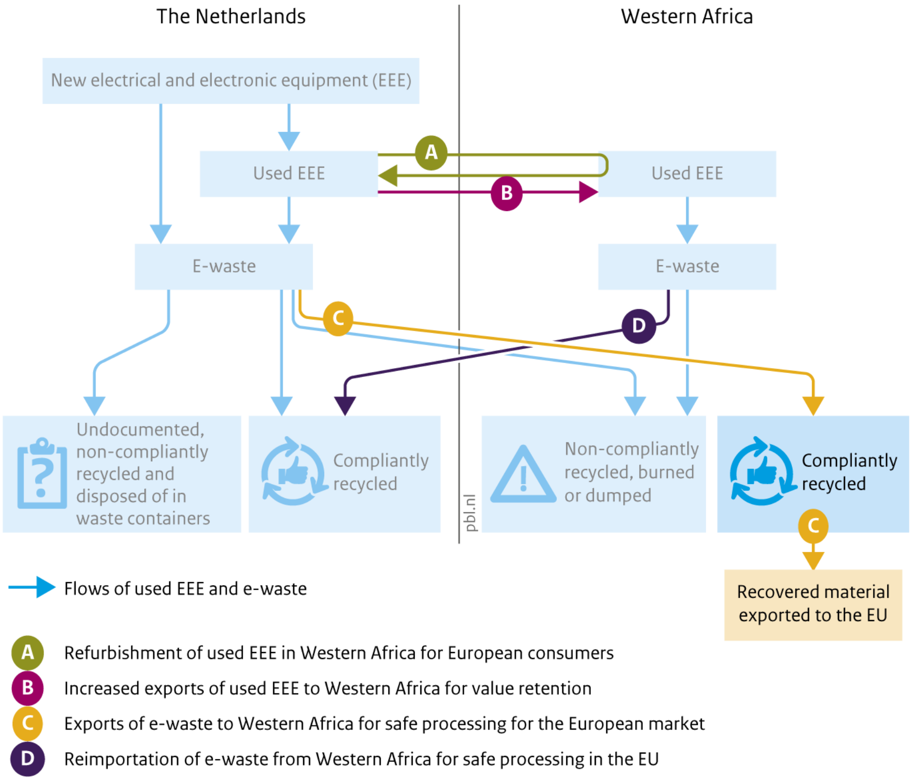
Refurbishment of used EEE in Western Africa for European consumers (A)
Under this scenario, used EEE is exported for refurbishment in Western Africa and transferred back to the EU as refurbished EEE. The used EEE does not become available on the local Western African market to consumers.

<u>Possible policy measure</u>: Set-up controlled refurbishment in Western Africa, under safe conditions. This mainly requires investment in the local repair and refurbishment sector.

<u>Potential effects per impact area</u>:

- Human Development: Potential increase in jobs in the repair and refurbishment industry. However, as used EEE from the EU does not enter the local market, it does not benefit local consumers.
- Pollution: Although used EEE from the EU does not become waste locally, refurbishment also creates waste from unusable or broken parts. Dependent on whether e-waste is handled in a safe manner, there could be a potential negative effect in terms of pollution.
- Resource efficiency: In general, more refurbishment results in lifetime extension and is therefore positive in terms of resource efficiency. If materials and parts in used EEE are used as much as possible before being discarded, this could be a resource-efficient strategy.

Figure 4.2
Flows of used-EEE and e-waste in circular economy strategies that include West Africa



Source: PBL

Challenges:

This approach could limit the local availability of used EEE, as the exports are aimed at refurbishment and export, not at providing more access to used EEE for local consumers. From the perspective of consumers in Western Africa it would therefore not be attractive, although on the other hand it could create local employment opportunities.

The question remains of what to do with waste produced as a by-product of the refurbishment activities. Similarly, there is a risk of exporting used EEE for refurbishment which on arrival turns out to be unsuitable and is therefore discarded, for instance because it is broken. This is in fact illegally exported e-waste, under the Basel Convention. For these reasons, this type of intervention would also require investment in waste management in Western Africa, good registration of used EEE imports and exports as well as precautions against negative externalities. Without addressing these points, this strategy could still contribute to the negative effects of e-waste management in Western Africa, and in the end mostly benefit European consumers.

Considerations:

Under this scenario, to achieve positive developments regarding all three impact areas requires setting up controlled refurbishment where work is done under safe conditions, as well as investment, creating infrastructure, monitoring and legislation in environmentally sound e-waste processing for the unusable materials, and precautions against negative social and environmental externalities.

Increased export of used EEE to Western Africa for value retention (B)
Under this scenario, to enhance value retention, more discarded used EEE is exported for reuse and lifetime extension in Western Africa.

Possible policy measures: Facilitate the increased export of second-hand, functioning electronic products to countries such as Ghana and Nigeria.

Potential effects per impact area:

- Human Development: The export of used EEE from the EU has a positive effect on the availability of affordable equipment for consumers. This trade would also support the repair and refurbishment industry and those dependent on it.
- Pollution: The effects on pollution are mainly related to what happens in the end-of-life stages when used EEE becomes e-waste.
- Resource efficiency: Extending the lifespan of used EEE in Western Africa results in higher resource efficiency locally, as materials remain in use for longer.

Challenges:

The key challenges of this scenario relate to what happens to used EEE once it becomes e-waste. If the aim of this approach is to increase positive impacts, it also requires substantial investment, developing monitoring systems and legislation in environmentally sound waste management in Western Africa. Effectively achieving this, on a large scale, will be costly and needs to have multi-stakeholder support. Enough funding will be required to support the transition to a safer system, to ensure that the negative existing effects of e-waste generation are not exacerbated even further. The question of which party should be responsible for the investment, such as producers of electronics, importers of used EEE, or national governments, is an important issue to resolve.

Considerations:

For this approach to be successful, it needs to address the role of the informal sector and workers already active in the e-waste value chain. Supporting the informal waste management sector in a transition to formal employment, thereby applying safe methods and benefiting from their existing skills and networks, could have significant added value and may address some of the challenges described above. Ideally, efforts would include employing local workers, while ensuring that work arrangements are formal and meet the standards of decent work, as laid out by the ILO (ILO, 2017).

Investment in these jobs could help improve labour conditions and support small enterprises to use safer methods. However, it is not clear whether safer e-waste processing would result in more or fewer jobs in waste processing. On the one hand, manual pre-treatment is more efficient than other options and research has shown that improvements regarding the management of waste could be an engine for job creation. On the other hand, automation could eventually also lead to lower demand for manual labour (Edmonds et al., 2019; McMahon et al., 2020).

Another aspect to consider is the need for increased checks on exports to ensure worthless, non-recyclable or dangerous items are not exported. Some used EEE and e-waste contains dangerous or environmentally damaging components that should not be exported at all, as the risk of harm is too high, and the added value in Western Africa is too low.

Additional transfer of funds is needed to make the transition possible from a largely informal to a formal waste management sector.

Funding an incentive-based collection framework could for example be part of an EPR system or could be partly or fully financed from import duties, as may be possible in Ghana under the Hazardous and Electronic Waste Control and Management Act (Act 917 of 2016) (Manhart et al., 2020) or a disposal fee incorporated in the purchase price.

Export of e-waste to Western Africa for safe processing for the European market (C)

Under this scenario, e-waste is exported to Western Africa, where a large labour force is available, in order to recover valuable materials for the European market. This strategy is not aimed at facilitating the trade in used EEE; the focus is on recovering valuable fractions from e-waste.

Possible policy measures: Set up an efficient, closely monitored and controlled collection of e-waste in Europe, intended for the recovery of materials in Western Africa. Investment in the environmentally sound treatment or pre-treatment of e-waste in Western Africa, to facilitate recovery of valuable materials and ensure the financial support and infrastructure is in place, for safe processing of fractions with no economic value.

Potential effects per impact area:

- Human Development: In terms of access to affordable used EEE, this approach does not contribute to or limit the flow of second-hand electronics and appliances to Western Africa. The effect is therefore regarded as neutral. In terms of employment, it may have a positive effect as more decent jobs could be created in waste management. It remains uncertain, however, whether there would be more or fewer employment opportunities, in both the short and the long term. In the short term, manual sorting and pre-treatment is more efficient in terms of material recovery, although, over time, automation may lead to a lower demand for manual labour.
- Pollution: Exporting and processing more e-waste under current circumstances has large negative effects in terms of pollution and is also illegal. A pre-condition for this scenario would therefore be the guarantee that e-waste is processed in a safe and environmentally sound manner. If this approach leads to the creation of large-scale environmentally sound e-waste management in Western Africa, this could have a positive effect in terms of pollution.
- Resource efficiency: Investing in waste management in Western Africa could lead to less waste being dumped or burned in the open (resource efficiency). If this is combined with the activities of informal collectors, this approach could prove to be very efficient. The question of who owns the extracted materials from the imported e-waste for safe processing is important in this approach, as substantial investments would need to be made in accessing the secondary materials that are to be recovered.

Challenges:

The export of hazardous waste to non-OECD countries is prohibited under the Basel Convention and the EU Waste Shipment Directive. Several African countries have also taken steps to prevent the import of e-waste, for example through the Bamako Convention. This scenario is thus only worth considering, if the environmentally sound e-waste management of domestically generated waste is guaranteed. This is something that is not even current practice in many EU countries. Even if environmentally sound waste management is guaranteed in receiving countries and there is the willingness to receive and process these shipments, this scenario is still challenging, time demanding and expensive. This is mainly due to the already existing, highly organised informal waste management sector, which would be hard to compete with in terms of costs.

Considerations:

Robust precautions would need to be taken, in order to prevent this strategy from worsening the e-waste problem in Western Africa, as the region is likely receiving more e-waste through other imports. This strategy would require substantial investments in environmentally sound waste management in Ghana and Nigeria before e-waste could be exported for safe processing, ideally employing local workers already active in the collection, dismantling and recycling of e-waste. Effective monitoring, reporting and certification could help to ensure that worthless, non-recyclable or hazardous fractions are not exported from the EU, and that Africa does not increasingly become the dumping ground for the EU's e-waste.

Reimportation of e-waste from Western Africa for processing in the EU (D)
As exported used EEE to Western Africa eventually becomes e-waste, in this scenario this e-waste is collected and transported back to Europe for safe and environmentally sound processing. There are existing examples of this approach, for example for mobile phones, tablets and laptops (Closing the Loop).

Possible policy measure:

As an example, producers of electronic equipment can set up take-back systems in Western Africa, as a form of extended producer responsibility (EPR), employing local collectors. In addition, investors can support local sustainable enterprises to provide collection services.

Potential effects per impact area:

- Human Development: This strategy mainly concerns e-waste and as such does not influence the access to affordable second-hand products, or jobs in the repair and refurbishment industry. For e-waste collectors and dismantlers, it could be positive regarding improved incomes and potentially safer working conditions.
- Pollution: Harmful substances are not released into the environment as waste is handled in an environmentally sound way in the EU. This has a positive impact on pollution but does also involve more transport of materials, from the EU to Africa and back again. This could be an additional source of greenhouse gas emissions.
- Resource efficiency: When used EEE is reused, repaired and refurbished *and* also managed in an environmentally sound manner at end-of-life, resource efficiency is highest. Transporting materials back and forth over large distances may however not be the most efficient way to address the problem of environmentally sound waste management.

Challenges:

The main challenge for this approach involves the inclusion of the informal waste collectors. Collectors will need to be paid a competitive price, to sell their goods to be exported back to Europe, without dismantling or recycling items to recover valuable materials first or selling to other traders (Manhart et al., 2020). This may be quite costly for certain equipment as there is already a market for recovered materials or valuable fractions, such as copper or gold, in which many costs are currently simply externalised through the informal sector. With many different stakeholders in the transboundary management of e-waste and used EEE, economic incentives in addition to transparency and regulation are required (Reuter et al., 2013). However, bringing external finances into the region could function as an incentive or an instrument to establish a more formalised e-waste management system and direct the flow of e-waste from Western Africa into the EU.

This system must address the collection and safe processing of worthless and dangerous waste fractions, such as lamps containing mercury and CRT monitors.

The issue of ownership can also come into play, here. It is unclear who would be responsible for which products, parts or materials. Similarly, it is not clear who would own the secondary materials recovered from retrieved e-waste.

These days, many low- and middle-income countries may not readily allow the re-exportation of e-waste, knowing that it contains valuable materials.

Considerations:

To address the main challenges, this approach would require working with informal local waste collectors and could improve current labour conditions to meet decent working standards. This includes investing in capacity-building, supporting workers to take necessary precautions to handle e-waste safely.

Furthermore, returning waste to the EU introduces an issue regarding ownership. If e-waste is transported to Europe for processing, countries such as Ghana and Nigeria lose a potentially valuable source of secondary materials. Western African countries might not be interested in re-exporting e-waste or recovered materials to the EU, especially if the e-waste has potential economic value. Obstacles to this trade should be identified and addressed, in order to make it more attractive for businesses to collect e-waste in Western Africa.

5 The way forward

As a result of globalised value chains, a transition to a circular economy can have an impact on international trade flows, affecting low- and middle-income countries. This is also the case when it comes to discarded electrical and electronic equipment (EEE). Impacts depend on the types of policies and strategies that the Netherlands adopts and can have different consequences in different regions. Impacts can be either positive or negative and are related to issues of human development, pollution and resource efficiency. Overall, the outcomes depend on 1) the type of circular economy strategy; 2) if and how low- and middle-income countries are part of the circular economy loops in the Netherlands or EU; and 3) the way e-waste is managed abroad. To benefit from the potential positive effects and mitigate any negative effects will require a sound understanding of the existing situation and challenges, as well as a clear perspective on what is necessary to prevent unwanted negative consequences. These conditions are discussed in this chapter.

5.1 Consider social benefits of circular economy strategies

The discussion around e-waste should include more than waste alone
There is enormous added value for human development in the transboundary trade in used EEE. It provides access to affordable, good quality electronic equipment and supports jobs in the repair and refurbishment industry. Not accounting for human development opportunities can contribute to unwanted consequences for both people and the environment. Furthermore, giving used EEE a second life abroad can be a resource-efficient strategy in terms of value retention. Countries such as Ghana and Nigeria already have a highly developed repair and refurbishment culture, and good quality second-hand electronics are in high demand. Extending the use phase of electronics in these countries may be more resource-efficient, in terms of material use, than processing and recycling discarded items that are still usable or repairable. Furthermore, due to technological and financial constraints, the recycling of electronic equipment will result in a net loss of materials for the time being — which means that optimising lifetime extension before recycling and recovery is a logical step (Reuter et al., 2013). The benefits for human development and the potential resource efficiency advantages are thus important elements in a broader discussion of e-waste.

Potential benefits for low- and middle-income countries are limited by the negative impacts of current waste processing practices
Second-hand, repaired or reused electronic products all eventually become e-waste, while the repair and refurbishment industry also produces scrap metal and other waste materials. Furthermore, export of used EEE is generally accompanied by worthless waste or items containing highly polluting or dangerous materials that have only limited to no benefits for human development. Without environmentally sound e-waste management in countries importing second-hand products, the benefits for human development are consequently accompanied by extreme pollution. Greenhouse gases and a wide range of hazardous substances released to air, soil and water negatively affect public health and the environment. Therefore, a strategy aimed at lifetime extension or refurbishment of used EEE abroad can only be successful if accompanied by investment in environmentally sound local e-waste management; and robust registration, reporting and monitoring systems for used EEE exports, as well as effective enforcement of existing legislation and restrictions.

5.2 Working with the informal sector, rather than against it

Environmentally sound waste processing is desirable in all approaches but requires substantial investments
Achieving positive effects for low- and middle-income countries in the transition to a circular economy in the Netherlands, requires investment in environmentally sound local e-waste management. The jobs in dismantling and recovering valuable fractions, especially through burning e-waste out in the open, are the most dangerous in e-waste management. People working in recycling and dismantling also have the lowest incomes and are often the most vulnerable and marginalised workers in the value chain (Edmonds et al., 2019). The investments required to tackle negative impacts without losing the positive effects are highest for e-waste management. On the other hand, e-waste processing is also the part of the value chain where the largest improvements can be achieved, both in terms of pollution and in terms of human development.

The potential for decent work opportunities in e-waste management is unclear
Robust research on employment opportunities in compliant e-waste processing is scarce. Existing research in Europe estimates that compliant e-waste pre-processing could create roughly 1 full-time job in pre-treatment per kilotonne of collected material (McMahon et al., 2020). If the same reasoning would be applied to the Western African context, sound e-waste management could hypothetically create roughly 400 jobs in pre-treatment, for the total weight of e-waste generated per year in the Netherlands. This estimation however excludes jobs in collection and the waste processing steps after pre-treatment. It is difficult to make projections about employment opportunities in the e-waste value chain for countries such as Ghana and Nigeria, due to their large informal labour force. 'New' jobs may in fact replace work currently already done by informal workers; alternatively, efforts could be made to help informal workers transition into the formal labour force. Therefore, more insight into the potential of formalised, decent work opportunities in e-waste management is required.

Successful efforts will need to include the informal sector
It is difficult for formal waste management facilities to compete with highly organised informal waste collectors, dismantlers and recyclers. The main reason for this is that the current system externalises the high costs associated with compliant reporting, decent work, taxes, processing worthless fractions and the environmentally sound processing of hazardous substances (Buchert et al., 2016; Manhart et al., 2020; Reuter et al., 2013). Efforts that are only aimed at restricting and limiting informal e-waste processing as much as possible — and which do not consider the alternatives available for people to make a living — would negatively impact the workers and communities that currently make a living from e-waste. Furthermore, this would only shift the problem to elsewhere, as it does nothing to address the increasing domestic generation of e-waste (Manhart et al., 2011). Strategies will thus need to recognise the informal system already in place, on which many people depend for their livelihoods (Adanu et al., 2020). It is not necessary to replace these jobs. Instead, efforts can be made to work with informal waste collectors, dismantlers and recyclers, and to support informal workers to adopt safer techniques and gain access to better equipment (Manhart et al., 2020; Woggsborg and Schröder 2018). Furthermore, such an approach should account for specific issues and structural barriers in the region, which drive the externalisation of costs for environmental protection, health and safety and decent labour conditions (Buchert et al., 2016). Social dialogue with workers, cooperatives and representative organisations is especially important for the recognition of workers, the formalisation of their work and the promotion of decent work (Edmonds et al., 2019).

Externally financed take-back systems offer opportunities to mitigate harm
Recycling of e-waste in the informal sector is driven by the value of the recovered metals and other materials. Economic incentives are needed to include the informal sector in environmentally sound waste management. One option that is often mentioned and has been tested in relatively small contexts is a take-back system. This usually consists of offering e-waste collectors and recyclers payment for handing e-waste that is then processed compliantly, instead of recovering the valuable fractions in an unsafe way. Such systems could be financed through a disposal fee incorporated in the purchasing price that is related to the weight or number of units of electrical and electronic equipment (EEE) on the national market, as a form of extended producer responsibility (EPR). Typical items collected are cables containing copper wires, lithium–ion batteries and ICT equipment. This approach may help to prevent the negative effects of informal recycling, while providing a way of attracting investment in e-waste management in the region.

New initiatives can draw lessons from existing programmes, such as the pilot project incentive system for the collection of waste cables by GIZ in Ghana (Manhart et al., 2020) or the Best of Both Worlds (Bo2W) project carried out in Egypt and Ghana (Buchert et al., 2016). Collected e-waste can be processed in officially registered recycling facilities in the region, such as Hinckley Recycling in Nigeria. If certified recycling facilities are unable to process certain volumes or specific types of e-waste, this waste can be transported to Europe for environmentally sound processing, as is done by the Closing the Loop company. In the CTL approach, companies in Europe can offset the impact of new ICT equipment they buy by contributing financially to the collection, transport and safe processing of a corresponding amount of e-waste from Western Africa. Thereby, the benefits of used EEE for human development continue, while limiting the negative, polluting impacts when they are discarded as e-waste.

That being said, a take-back system is not without its challenges. For example, there will still be competition with other buyers, who might pay more for extracted materials and so provide a stronger incentive to continue unsafe recycling practices. Furthermore, these approaches do not have any straightforward answers for how to deal with worthless items, which only cost money to recycle. For the collection and export of hazardous waste to the EU for compliant recycling, a strong business case is needed to finance the operation (CTL, 2020). EPR can help formalise and finance the collection and treatment of these worthless items.

Including the informal sector requires a broad discussion with relevant stakeholders, beyond the private sector and governments
The challenge of improving labour conditions in waste management in low- and middle-income countries is not new, and much can be learned from actors familiar with this issue. For example, involving parties that promote safe and decent work for informal workers can provide insights into both barriers and opportunities that may not be immediately obvious to outsiders. Including civil society stakeholders can also help to strengthen and legitimise the chosen strategy, as these organisations can facilitate communication and capacity-building with workers and communities, and act as watchdogs to ensure people’s rights are respected. Organisations such as IndustriALL Global Union or the International Organisation of Employers (IOE) are examples of such parties. Stakeholder consultation could be further expanded, to include governments and workers’ and employers’ organisations. Moving forward with new initiatives without the knowledge, experiences and support of the people or communities affected by the plans, carries the risk of initiatives being ineffective, short-lived or even having adverse impacts.

Compliant waste management could be strengthened by more fundamental and cross-cutting changes in the value chain
While there is plenty of progress to be made concerning existing electronic products and how they are processed at end-of-life, new electronic products could also be designed with repair, recycling and processing already in mind. Dependent on the focus of the redesign, this could make products more modular, thereby making it easier to process and reuse components. Furthermore, by using alternative materials and production methods, products could become less toxic and thus less harmful for people and the environment when processed. As redesign affects new electronics entering the Dutch market, the impacts on low- and middle-income countries will only become apparent after the products are discarded.

5.3 Improve transparency and monitoring of trade flows

How international trade flows are affected depends on the role of low- and middle-income countries
With respect to international trade, several global trends in response to a circular economy transition could be expected, such as the reduced trade in primary raw materials, increased trade in secondary materials, increased trade in recyclable waste, increased trade in second-hand products, and increased trade in services (Van der Ven, 2020). However, these changes in trade flows are uncertain and depend on several factors, such as the type of circular economy strategy that is pursued, and if and how low- and middle-income countries become part of that circular economy. When policies are directed to keeping discarded electronic equipment within the EU as much as possible, trade in used EEE will most likely decrease. Trade in e-waste between non-OECD countries and the EU is already restricted under the Basel Convention. Circular economy policies will probably not affect these trade flows, apart from reducing in the share of e-waste that is illegally mixed in with second-hand products. Nevertheless, several scenarios could be envisioned in which low- and middle-income countries become part of the circular economy loops of the Netherlands, focusing for example on refurbishment, lifetime extension and waste processing. Such strategies can potentially increase trade in second-hand products, as well as in services and recovered, secondary materials.

Policy strategies that increase transboundary waste flows deserve scrutiny
Increasing e-waste generation is expected to continue at a rapid rate. Given the current challenges and low rates of environmentally sound e-waste management in low- and middle-income countries, it is not likely that they will be able to easily handle increasing waste flows in an environmentally sound manner. Furthermore, while trade in used EEE for reuse abroad is possible, other trade flows are largely restricted under current regulation and international agreements such as the Basel Convention and the WSR. Increased trade in discarded electrical and electronic equipment (EEE) for reuse, for repair and refurbishment, or of environmentally sound processing, has the potential to cause a lot of harm to public health and the environment. Nevertheless, it could be argued that, under the right conditions, transboundary trade in discarded electronic products can provide opportunities for countries that have a comparative advantage in sorting and processing activities. Among other conditions, this requires improved policy coherence between circular economy measures and trade and development cooperation policies (IEEP, 2019; Van der Ven, 2020).

Improved reporting, monitoring and certification is essential
In addition to strategies to improve processing of the growing mountains of e-waste in low- and middle-income countries, imports of worthless, non-recyclable or dangerous items into these countries should also be avoided as much as possible.

This requires further improvements in reporting, monitoring and transparency systems, as well as restrictions and enforcement on the transboundary movement of worthless and hazardous products and fractions. Implementing such steps calls for improved registration of exports of used EEE for reuse in, for instance, the *Nationaal (W)EEE Register*; an increase in the inspection of recyclers; mandatory handover of e-waste to certified recyclers; and increased certification of recyclers (Baldé et al., 2020a). Trade policies can play a facilitating role in this regard. For example, by supporting the international harmonisation of definitions and quality standards (including global eco-labelling schemes) linked to waste recycling, and circularity more broadly (Van der Ven, 2020; IEEP, 2019).

5.4 A just transition requires inclusive policies

There are many options to limit environmental damage as a result of the transboundary movement of e-waste (e.g. restrictions on export, environmentally sound management, redesign). However, to ensure that the circular economy transition is in line with development cooperation, successful efforts in the long term will require a broader perspective. This means paying attention to social considerations related to poverty, inequality and decent work.

Recognise and address people's needs and challenges in the e-waste value chain
An important first step in this effort is to recognise the different needs, challenges and opportunities people face in low- and middle-income countries. To influence any positive change in how e-waste is managed in Western Africa, it is necessary to consider the reality currently faced by workers at various stages of the value chain. This includes an understanding of how the system currently operates, for example by recognising the co-existence of the formal and informal sectors, as the two are interwoven. In the end, it will be key to transform existing networks of waste management, while putting mechanisms in place that ensure the livelihoods of workers are not negatively affected. The ILO states that social dialogue with workers, cooperatives and representative organisations is critical in this regard (ILO, 2019). This is especially important for the recognition of workers, the formalisation of their work and the promotion of decent work (Edmonds et al., 2019).

Investment in an inclusive circular economy beyond national borders could be further encouraged
Creating an enabling environment for small and medium-sized enterprises (SMEs) that are already active in the e-waste management area can help generate decent jobs. SMEs can also provide a public–private solution for strong e-waste management infrastructure (ILO, 2014). In both Ghana and Nigeria, enterprises that try to achieve this already exist, for example City Waste Recycling (CWR) in Ghana, which is part of an EU-funded project called E-MAGIN that aims to formalise and improve the e-waste management value chain in Ghana.[3]

Ultimately, circular economy strategies that fail to understand and address the interlinkages between the dimensions of human development, pollution and resource efficiency of the e-waste challenge, will at best miss an opportunity for an inclusive transition, and at worst undermine the achievement of the UN Sustainable Development Goals.

[3] E-MAGIN – e-waste management in Ghana: www.e-magin-ghana.com/.

References

Adanu SK, Gbedemah SF and Attah MK. (2020). Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie, Ghana. Heliyon 6: pp. e04548

Amoyaw-Osei Y, Agyekum OO, Pwamang JA, Mueller E, Fasko R and Schluep M. (2011). Ghana e-Waste Country Assessment. SBC e-Waste Africa Project. Green Advocacy Ghana (Green Ad.), Environmental Protection Agency (EPA), Secretariat of the Basel Convention (SBC), UN Environment Programme (UNEP), Eidgenossische Materialprufungs- und Forschungsanstalt (EMPA).

Aoshima K. (2012). Itai-itai disease: cadmium-induced renal tubular osteomalacia. Nihon Eiseigaku Zasshi 67: pp. 455–63.

Asante KA, Adu-Kumi S, Nakahiro K, Takahashi S, Isobe T, Sudaryanto A, Devanathan G, Clarke E, Ansa-Asare OD, Dapaah-Siakwan S and Tanabe S. (2011). Human exposure to PCBs, PBDEs and HBCDs in Ghana: Temporal variation, sources of exposure and estimation of daily intakes by infants. Environment international 37: pp. 921–928.

Asongu SA and Le Roux S. (2017). Enhancing ICT for inclusive human development in Sub-Saharan Africa. Technological Forecasting and Social Change 118: pp. 44–54.

ATSDR (2005). Toxicological Profile for Nickel (ed Agency for Toxic Substances and Disease Registry), Atlanta, Public Health Service.

ATSDR (2007). Public Health Statement: Lead (ed Agency for Toxic Substances and Disease Registry), Atlanta, Public Health Service.

ATSDR (2011). Polychlorinated Biphenyls (PCBs) (ed Agency for Toxic Substances and Disease Registry), Atlanta, CDC – Toxic Substances Portal.

ATSDR (2012a). Chromium Tox FAQs (ed Agency for Toxic Substances and Disease Registry), Atlanta, GA: USA, Division of Toxicology and Human Health Sciences.

ATSDR (2012b). Toxicological Profile for Manganese. (ed Agency for Toxic Substances and Disease Registry), Atlanta, GA USA, Public Health Service.

ATSDR (2012c). Public Health Statement Cadmium (ed Agency for Toxic Substances and Disease Registry), Division of Toxicology and Human Health Sciences.

Awasthi AK and Li J. (2017). Management of electrical and electronic waste: A comparative evaluation of China and India. Renewable and Sustainable Energy Reviews 76.

Baldé CP and van den Brink S. (2020). Monitoring Exports for Reuse in the Netherlands. United Nations University and United Nations Institute for Training and Research, Bonn.

Baldé CP, van den Brink S, Forti V, van der Schalk A and Hopstaken F. (2020a). The Dutch WEEE Flows 2020, What happened between 2010 and 2018. United Nations University (UNU) / United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, Bonn.

Baldé CP, Wagner M, Iattoni G and R. K. (2020b). In-depth Review of the WEEE Collection Rates and Targets in the EU-28, Norway, Switzerland, and Iceland. United Nations University (UNU) / United Nations Institute for Training and Research (UNITAR) – co-hosting the SCYCLE Programme, Bonn.

Barceloux DG and Barceloux D. (1999). Nickel. Journal of Toxicology: Clinical Toxicology 37: pp. 239–258.

Batinic B, Vaccari M, Vassiliki S, Kousaiti A, Gidarakos E, Marinkovic T and Fiore S. (2018). Applied WEEE pre-treatment methods: Opportunities to maximizing the recovery of critical metals. Global Nest Journal.

Baxter J, Lyng KA, Askham C and Hanssen OJ. (2016). High-quality collection and disposal of WEEE: Environmental impacts and resultant issues. Waste Management 57: pp. 17–26.

BIO Intelligence Service (2013). Equivalent conditions for waste electrical and electronic equipment (WEEE) recycling operations taking place outside the European Union, final report prepared for the European Commission, DG Environment, Brussels.
Bonnet F, Vanek J and Chen M. (2019). Women and Men in the Informal Economy — A Statistical Brief. WIEGO, Manchester.
Bosch S, van Exter P, Sprecher B, de Vries H and Bonenkamp N. (2019). Metaalvraag van elektrisch vervoer — Op weg naar duurzaam, eerlijk en toekomstbestendig personenvervoer [Towards sustainable, fair and future-proof passenger transport (in Dutch)]. METABOLIC, Copper8, Leiden University, Leiden.
Buchert M, Manhart A, Mehlhart G, Degreif S, Bleher D, Schleicher T, Meskers C, Picard M, Weber F, Walgenbach S, Kummer T, Blank R, Allam H, Meinel J and Ahiayibor V. (2016). Transition to sound recycling of ewaste and car waste in developing countries — Lessons learned from implementing the Best-of-two-Worlds concept in Ghana and Egypt. A synthesis report of the project Global Circular Economy of Strategic Metals — Best-of-two-Worlds approach (Bo2W)(FKZ 033R097A – D). Oeko-Institut e.V., Umicore, Johnson Controls Power Solutions, Vacuumschmelze GmbH & Co. KG, CEDARE, City Waste Recycling, Freiburg.
CDC (2009). Polycyclic Aromatic Hydrocarbons (PAHs) (ed The Centers for Disease Control and Prevention), Atlanta, GA: USA, Department of Health and Human Services USA.
Circle Economy (2020). Exploring the global environmental and socio-economic effects of pursuing a circular economy: case study on jeans and mobile phones. Circle Economy, Amsterdam.
CTL (2020). Making a business case for African battery recycling, Closing the Loop: Amsterdam.
De Ridder M. (2017). Internationale effecten circulaire economie vragen om moreel en strategisch leiderschap [International impact circular economy calls for moral and strategic leadership (in Dutch)]. Internationale Spectator.
ECHA (2018). Background document to the Opinion on the Annex XV dossier proposing restrictions on Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances (eds Committee for Risk Assessment (RAC) and Committee for Socio-economic Analysis (SEAC)), European Chemicals Agency, Helsinki.
Edmonds CN, Goel S, Nakagome H, Kemp W and Lindström E. (2019). Decent work in the management of electrical and electronic waste (e-waste). ILO: Geneva, Switzerland.
European Union (2012). Directive 2012/19/EU of the European Parliament and the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE), Brussels, Belgium.
European Commision (2017). Communication From The Commission To The European Parliament, The Council, The European Economic and Social Committee and The Committee Of The Regions on the 2017 list of Critical Raw Materials for the EU COM/2017/0490.
European Commision (2017). Communication From The Commission To The European Parliament, The Council, The European Economic and Social Committee and The Committee Of The Regions on the 2017 list of Critical Raw Materials for the EU COM/2017/0490.
European Council (2006). Regulation (EC) No. 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste.
European Parliament and the European Council (2000). Directive 2000/53/EC on end-of life vehicles — Commission Statements.
European Parliament and the European Council (2011). Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment Text with EEA relevance.
Forti V, Baldé CP, Kuehr R and Bel G. (2020). The Global E-waste Monitor 2020, Quantities, flows and the circular economy potential. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) — co-hosted SCYCLE Programme,

International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.
Goel S. (2019). From waste to jobs decent work challenges and opportunities in the management of e-waste in Nigeria. International Labour Organization.
Government of Canada (2010). Products that contain mercury: switches and relays.
Grant K, Goldizen FC, Sly PD, Brune M-N, Neira M, van den Berg M and Norman RE. (2013). Health consequences of exposure to e-waste: a systematic review. The Lancet Global Health 1: pp. e350–e361.
Guo Y, Huo X, Wu K, Liu J, Zhang Y and Xu X. (2012). Carcinogenic polycyclic aromatic hydrocarbons in umbilical cord blood of human neonates from Guiyu, China. Science of The Total Environment 427–428: pp. 35–40.
Hare E. (2017). Diffusion Barrier Plating in Electronics. (ed I SEM lab).
Heacock M, Kelly CB, Asante KA, Birnbaum LS, Bergman ÅL, Bruné M-N, Buka I, Carpenter DO, Chen A and Huo X. (2016). E-waste and harm to vulnerable populations: a growing global problem. Environmental health perspectives 124: pp. 550–555.
Huisman J, van der Maesen M, Eijsbouts RJJ, Wang. F, Baldé CP and Wielenga CA. (2012). The Dutch WEEE Flows. United Nations University and ISP — SCYCLE., Bonn, Germany.
Huisman J, Botezatu I, Herreras L, Liddane M, Hintsa J and Luda di Cortemiglia V. (2015). Countering WEEE Illegal Trade (CWIT) Summary Report, Market Assessment, Legal Analysis, Crime Analysis and Recommendations Roadmap.
IEEP (2019). EU circular economy and trade: Improving policy coherence for sustainable development.
Keesman B. (2019). Market Survey Waste and Circular Economy in Ghana. Commissioned by the Netherlands Enterprise Agency. Dutch Ministry of Foreign Affairs, The Hague.
Ministry of IenM (2014). Regeling van de Staatssecretaris van Infrastructuur en Milieu nr. IENM/BSK-2014/14758, houdende vaststelling regels met betrekking tot afgedankte elektrische en elektronische apparatuur (Regeling afgedankte elektrische en elektronische apparatuur) [regulation on discarded electrical and electronical equipment] Dutch former Ministry of Infrastructure and the Environment, The Hague.
Ministry of IenM and Ministry of EZ (2016). A Circular Economy in the Netherlands by 2050 — Government-wide Programme for a Circular Economy. Dutch former Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, The Hague.
ILO (2014). An enabling environment for sustainable enterprises (ed TIL Organization), Geneva.
ILO (2017). Transition from the Informal to the Formal Economy Recommendation 2015 (No. 204): Workers' guide / International Labour Office, Bureau for Workers' Activities (ACTRAV). ILO, Geneva.
ILO (2019). *Decent work in the management of electrical and electronic waste (e-waste),* Issues paper for the Global Dialogue Forum on Decent Work in the Management of Electrical and electronic waste (E-waste) (Geneva, 9–11 April 2019), International Labour Office, Sectoral Policies Department, ILO: Geneva.
Işıldar A, Rene ER, van Hullebusch ED and Lens PNL. (2018). Electronic waste as a secondary source of critical metals: Management and recovery technologies. Resources, Conservation and Recycling 135: pp. 296–312.
Kim S, Xu X, Zhang Y, Zheng X, Liu R, Dietrich K, Reponen T, Ho S-m, Xie C, Sucharew H, Huo X and Chen A. (2019). Metal concentrations in pregnant women and neonates from informal electronic waste recycling. Journal of Exposure Science & Environmental Epidemiology 29: pp. 406–415.
Kyere V, Greve K, Asampson A, Amoako D, Aboh K and Cheabu B. (2018). Contamination and Health Risk Assessment of Exposure to Heavy Metals in Soils from Informal E-Waste Recycling Site in Ghana. Emerging Science Journal 2(6): 428.
Lenz K, Afoblikame R, Kercher SY, Kotoe L, Schluep M, Smith E, Schroder P and Valdivia S. (2019). E-waste training manual, Vienna.

Lepawsky J. (2015). The changing geography of global trade in electronic discards: time to rethink the e-waste problem. The Geographical Journal 181: pp. 147–159.
Lin Y, Xu X, Dai Y, Zhang Y, Li W and Huo X. (2016). Considerable decrease of antibody titers against measles, mumps, and rubella in preschool children from an e-waste recycling area. Science of The Total Environment 573: pp. 760–766.
Lucas P, Kram T and Hanemaaijer A. (2016). Potential effects of circular economy policies in the EU and the Netherlands on developing countries. PBL Netherlands Environmental Assessment Agency, The Hague.
Magalini F and Huisman J. (2018). WEEE Recycling Economics — The shortcomings of the current business model. United Nations University, UNU — VIE SCYCLE, Bonn.
Manhart A, Osibanjo O, Aderinto A and Prakash S. (2011). Informal e-waste management in Lagos, Nigeria — socio-economic impacts and feasibility of international recycling co-operations. Final report of component 3 of the UNEP SBC E-waste Africa Project. Öko-Institut e.V., Lagos and Freiburg.
Manhart A, Akuffo B, Attafuah-Wadee K, Atiemo S, Batteiger A, Jacobs J and Osei N. (2020). Incentive Based Collection of E-Waste in Ghana. Findings from the pilot incentive system for waste cables from March 2018 to August 2019 Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Accra.
McMahon K, Ryan-Fogarty Y and Fitzpatrick C. (2020). Estimating job creation potential of compliant WEEE pre-treatment in Ireland. Resources, Conservation & Recycling.
Mumtaz M and George J (1995). Toxicological profile for polycyclic aromatic hydrocarbons (ed USDOHaHS-PH Service).
Nationaal (W)EEE Register (2019). Report 2019. Nationaal (W)EEE Register, Zoetermeer.
Nnorom IC and Odeyingbo OA. (2020). 14 — Electronic waste management practices in Nigeria. In: MNV Prasad, M Vithanage and A Borthakur (eds.) Handbook of Electronic Waste Management. Butterworth-Heinemann, pp. 323–354.
Odeyingbo O, Nnorom I and Deubzer O. (2017). Person in the Port Project: Assessing Import of Used Electrical and Electronic Equipment into Nigeria. UNU-ViE SCYCLE and BCCC Africa, Bonn.
Ogungbuyi O, Nnorom IC, Osibanjo O and Schluep M. (2012). E-waste country assessment Nigeria. The Secretariat of the Basel Convention and the Swiss Federal Laboratories for Materials Science and Technology — Empa.
Ohajinwa CM, van Bodegom PM, Vijver MG and Peijnenburg W. (2017). Health Risks Awareness of Electronic Waste Workers in the Informal Sector in Nigeria. International Journal of Environmental Research and Public Health 14.
Ohajinwa CM, van Bodegom PM, Osibanjo O, Xie Q, J. C, M.G. V and Peijnenburg WJGM. (2019). Health Risks of Polybrominated Diphenyl Ethers (PBDEs) and Metals at Informal Electronic Waste Recycling Sites. International Journal of Environmental Research and Public Health 16.
Organization of African Unity. (1991). Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa. International Legal Materials. 30: pp. 773–799.
Osibanjo O. (2015). Gender and e-waste management in Africa.
Oteng-Ababio M and Grant R. (2020). 15 — E-waste recycling slum in the heart of Accra, Ghana: the dirty secrets. In: MNV Prasad, M Vithanage and A Borthakur (eds.) Handbook of Electronic Waste Management. Butterworth-Heinemann, pp. 355–376.
Parajuly KK, R.; Awasthi, A. K.; Fitzpatrick, C.; Lepawsky, J.; Smith E.; Widmer, R.; Zeng, X. (2019). Future e-waste scenarios. StEP (Bonn), UNU ViE-SCYCLE (Bonn) & UNEP IETC (Osaka).
Prakash S, Manhart A, Amoyaw-Osei Y and Agyekum OO. (2010). Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana. Oko-InstituteV in cooperation with Ghana Environmental Protection Agency (EPA) & Green

Advocacy Ghana. Dutch former Ministry of Housing, Spatial Planning and the Environment (VROM-Inspectorate), The Hague.
Prins AG and Rood T (2020). Op weg naar een robuuste monitoring van de circulaire economie [Towards robust monitoring of the circular economy (in Dutch)]. Resultaten-2019 van het Werkprogramma Monitoring en Sturing Circulaire Economie, PBL Netherlands Environmental Assessment Agecy, The Hague.
Rademaker M. (2017). De Europese circulaire economie`en ontwikkelingslanden [The European circular economy and developing countries (in Dutch)].
Rao MD, Singh KK, Morrison CA and Love JB (2020). Challenges and opportunities in the recovery of gold from electronic waste. RSC Advances 10(8): 4300–4309.
Reuter MA, Hudson C, van Schaik A, Heiskanen K, Meskers C and Hagelüken C. (2013). Metal Recycling: Opportunities, Limits, Infrastructure, A Report of the Working Group on the Global Metal Flows to the International Resource Panel. UNEP, Paris.
Reuters (2020) Apple pushes recycling of iPhone with 'Daisy' robot. Available at: https://www.reuters.com/article/us-usa-minerals-recycling/apple-pushes-recycling-of-iphone-with-daisy-robot-idUSKBN1Z925S, 24 November 2020.
Salehabadi D. (2013). Transboundary Movements of Discarded Electrical and Electronic Equipment — Solving the E-Waste Problem (StEP) Green Paper Cornell University.
SBT. (2015). Report of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal on the work of its twelfth meeting. Secretariat of the Basel Convention, Geneva.
Schluep M, Manhart A, Osibanjo O, Rochat D, Isarin N and Mueller E. (2011). Where are WEee in Africa? Findings from the Basel Convention E-waste Africa Programme. Secretariat of the Basel Convention, Geneva.
Schröder P, Anggraeni K and Weber U. (2019). The Relevance of Circular Economy Practices to the Sustainable Development Goals. Journal of Industrial Ecology 23: pp. 77–95.
Schröder P. (2020). Promoting a Just Transition to an Inclusive Circular Economy. Chatham House, London.
Statista. (2020) Rare earth reserves worldwide as of 2019, by country (in 1,000 metric tons REO)*. https://www.statista.com/statistics/277268/rare-earth-reserves-by-country/#:~:text=According%20to%20estimates%20by%20the,some%2044%20million%20metric%20tons.&text=With%20over%20132%2C000%20metric%20tons,these%20amounts%20in%20Inner%20Mongolia. 19 November 2020.
Step Initiative (2014). One Global Definition of E-Waste. Solving the E-Waste Problem (Step), Bonn.
Thiébaud E, Hilty L, Schluep M, Böni H and Faulstich M. (2018). Where Do Our Resources Go? Indium, Neodymium, and Gold Flows Connected to the Use of Electronic Equipment in Switzerland. Sustainability 10(8): 2658.
Trading Economics. (2020) Nigeria National Minimum Wage 2018–2020 Data. https://tradingeconomics.com/nigeria/minimum-wages, 9 November 2020.
Umair S, Björklund A and Petersen EE. (2015). Social impact assessment of informal recycling of electronic ICT waste in Pakistan using UNEP SETAC guidelines. Resources, Conservation and Recycling 95: pp. 46–57.
UN. (2015). Transforming our world: The 2030 Agenda for Sustainable Development. United Nations, New York.
UNCED (1992). United Nations Conference on Environment and Development. A.CONF.15/5/Rev.1., Rio de Janeiro.
UNEP (2017). Stockholm Convention on Persistent Organic Pollutants (Pops). Texts and Annexes. Revised in 2017. The Secretariat of the Stockholm Convention, Geneva.
United States Geological Survey (2020). Rare Earths. Mineral Commodity Summaries.
van der Ven C. (2020). The Circular Economy, Trade, and Development: Addressing spillovers and leveraging opportunities. Tulip consulting, Geneva.

van Exter P, Bosch S, Schipper B, Sprecher B and Kleijn R. (2018). Metal Demand for Renewable Electricity Generation in The Netherlands — Navigating a Complex Supply Chain. METABOLIC, Universiteit Leiden & Copper8.
Wittsiepe J, Fobil JN, Till H, Burchard G-D, Wilhelm M and Feldt T. (2015). Levels of polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/Fs) and biphenyls (PCBs) in blood of informal e-waste recycling workers from Agbogbloshie, Ghana, and controls. Environment international 79: pp. 65–73.
Woggsborg A and Schröder P. (2018). Nigeria's E-Waste Management: Extended Producer Responsibility and Informal Sector Inclusion. 1.
Wu K, Xu X, Peng L, Liu J, Guo Y and Huo X. (2012). Association between maternal exposure to perfluorooctanoic acid (PFOA) from electronic waste recycling and neonatal health outcomes. Environment international 48: pp. 1–8.
Xu X, Yang H, Chen A, Zhou Y, Wu K, Liu J, Zhang Y and Huo X. (2012). Birth outcomes related to informal e-waste recycling in Guiyu, China. Reproductive Toxicology 33: pp. 94–98.
Zeng X, Xu X, Boezen HM and Huo X. (2016). Children with health impairments by heavy metals in an e-waste recycling area. Chemosphere 148: pp. 408–415.
Zhang M, Buekens A, Jiang X and Li X. (2015). Dioxins and polyvinylchloride in combustion and fires. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA 33: pp. 630–643.

Appendix A: Expert consultation

Table A.1 Experts consulted for this study

Name	Affiliation
Chimere May Ohajinwa	Principal Consultant at C-Circle Research, Abuja, Nigeria.
Olusegun A. Odeyingbo	Department of Environmental Technology, Chair of Circular Economy and Recycling Technology, Technische Universität Berlin, Germany.
Markus Spitzbart	Head of Programme 'Sustainable E-Waste Management in Ghana', GIZ Accra, Ghana.
Bert Keesman	Owner/Director at MetaSus, Weesp, Netherlands.
Jeroen van der Tang	Nederlandse Verwijdering Metalelektro Producten (NVMP) — NL Digital, Breukelen, Netherlands.
Joost de Kluijver	Director and Founder at Closing the Loop, Amsterdam, Netherlands.
Benjamin Sprecher	Assistant professor Institute of Environmental Sciences (CML) Leiden University, Leiden, Netherlands.
Enno Christan	Senior inspector — The Human Environment and Transport Inspectorate (Inspectie Leefomgeving en Transport, ILT), Ministry of Infrastructure and Water Management, The Hague, Netherlands.
Adegun Oluwatobi	Business Process Analyst at Rensource Energy, Social Entrepreneur, Founder and CEO of Verde Impacto, Lagos, Nigeria.
Lebene Ledi	Principal Consultant at Maiden Environmental Services Tema, Ghana.
Shreya Ashu Goel	Junior Project Officer at International Labour Organization (ILO), Geneva, Switzerland.
Patrick Schröder	Senior Research Fellow, Energy, Environment and Resources Programme at Chatham House, London, United Kingdom.
Jim Puckett	Executive director and founder of Basel Action Network (BAN), Seattle, United States.
Peter Frijns	Senior Policy Officer — Ministry of Infrastructure and Water Management, The Hague, Netherlands.
Hans Spiegeler	Policy Officer - Ministry of Infrastructure and Water Management, The Hague, Netherlands.

Appendix B: Data used to measure exports

There are various data sources and classifications that can be used to measure the exports from the Netherlands. There is not one single data source that comprehensively describes all e-waste and used EEE exports. Thus, the monitoring of exports has to be done by integrating various data sources in different classifications. This must be done considering that some data sources can be partly overlapping, thus having the risk of double counting, or that there are no suitable data sources available for some of the flows and products.

In general, the classifications to measure the transboundary movement of e-waste are not adequate. The classifications of the Basel Convention only measure the legal flows and only that of hazardous substances. The data reported under the Basel Convention will also overlap with data in the *Nationaal (W)EEE Register* and, again, the latter only represent legal flows. For especially the illegal e-waste exports, conventional waste statistics and classifications do not suffice. Foreign Trade Statistics are not ideal, as the e-waste or used EEE codes are registered using the same codes as for new equipment. Thus, additional data handling steps need to be performed to extract the used EEE and e-waste exports. Also, e-waste is also exported stuffed into second-hand vehicles, and not always registered.

In this study, the following data sources and methodologies are used to measure the quantities and destinations of the exports.

1. Legal e-waste export
For the legal e-waste exports, the data from the *Nationaal (W)EEE Register* were used.

2. Export for Reuse
There was not one data source that covered the exports for reuse entirely for all products. We used the detailed from a recent study, 'Monitoring Export for Reuse in the Netherlands', (Baldé and Van den Brink, 2020). In that study, all modalities of used EEE exports and data sources were used. The six data sources and methods were:

1. The voluntary registration of exports for reuse in the *Nationaal (W)EEE Register*. This register does not include destination information.
2. Desktop research of recently conducted studies. The destination of the exports is not disclosed in the studies.
3. Trade data price analysis: export of mixed new and used electrical and electronic equipment. The records of used EEE exports were extracted using a price differentiation of the export flow. If the price was below a certain threshold, it was marked as second hand. The threshold has been determined per UNU-KEY, and usually comprised of 30% of the median price. The destination is known in the trade statistics and has been taken as an average of the years 2010–2018.
4. Trade data on second-hand vehicles: used electrical and electronic equipment are exported in vehicles to Western Africa. The average load of a second-hand vehicle, also considering the empty vehicles, has been obtained from Nigerian empirical work from a person in the port (Odeyingbo et al., 2017).
5. Educated guess of the reusability per UNU-KEY. In an upcoming study, the full mass balance of e-waste has been made per UNU-KEY. An educated guess has been made on gap of the mass balance on the reusability and exportability of a used EEE / e-waste item. The destination was not known.

6. Data from the LUCA Testing Facility in Amsterdam. This facility, located at the Port of Amsterdam, where used EEE can be tested prior to shipment to Africa. Documentation on the number of exported appliances were obtained from this testing facility. Those were converted into weight, using the appliances' unit weights. Although the destination was unspecified, most is assumed to have gone to Western Africa.

The outcomes per method were compared per UNU-KEY. Then the outcomes of the best method per UNU-KEY was chosen, and it was ensured that no double counting took place. The outcomes are in line with the overall results of the mass balance of e-waste in the Dutch WEEE Flows study 2020 (Baldé et al., 2020a).

No suitable data source was found to monitor Dutch exports to neighbouring countries, such as Belgium and Germany. It could be that a part of the used EEE exports is re-exported to low- and middle-income countries.

3. Illegal e-waste exports

Illegal exports of e-waste are notoriously difficult to measure. It would be possible to construct it from inspection data and registries in the Dutch ports, however, a quantitative study has not been performed in the Netherlands. At European level, the mass balance for Europe has been determined in the Countering e-waste Illegal Trade Project (Huisman et al., 2015) and fragmented data are available on imports into the Nigerian ports (Odeyingbo et al., 2017; Ogungbuyi et al., 2012).

Appendix C: Classification of EEE and e-waste

Table C.1 Links between UNU keys and categories of the EU WEEE Directive and Nationaal (W)EEE Register

UNU-KEY	Full name	EU WEEE Directive (EU-6)	Nationaal (W)EEE Register
0001	Central Heating (household installed)	4	1c
0002	Photovoltaic Panels (incl. inverters)	4	4d
0101	Professional Heating & Ventilation (excl. cooling equipment)	4	1d
0102	Dishwashers	4	1c
0103	Kitchen (e.g. large furnaces, ovens, cooking equipment)	4	1c
0104	Washing Machines (incl. combined dryers)	4	1c
0105	Dryers (wash dryers, centrifuges)	4	1c
0106	Household Heating & Ventilation (e.g. hoods, ventilators, space heaters)	4	1c
0108	Fridges (incl. combi-fridges)	1	1a
0109	Freezers	1	1a
0111	Air Conditioners (household installed and portable)	1	1a
0112	Other Cooling (e.g. dehumidifiers, heat pump dryers)	1	1a
0113	Professional Cooling (e.g. large air conditioners, cooling displays)	1	1b
0114	Microwaves (incl. combined, excl. grills)	5	1c
0201	Other Small Household (e.g. small ventilators, irons, clocks, adapters)	5	2
0202	Food (e.g. toaster, grills, food processing, frying pans)	5	2
0203	Hot Water (e.g. coffee, tea, water cookers)	5	2
0204	Vacuum Cleaners (excl. professional)	5	2
0205	Personal Care (e.g. toothbrushes, hair dryers, razors)	5	2
0301	Small IT (e.g. routers, mice, keyboards, external drives & accessories)	6	3c
0302	Desktop PCs (excl. monitors, accessories)	6	3c
0303	Laptops (incl. tablets)	2	3b
0304	Printers (e.g. scanners, multifunctionals, faxes)	6	3c

0305	Telecom (e.g. (cordless) phones, answering machines)	6	3c
0306	Mobile Phones (incl. smartphones, pagers)	6	3c
0307	Professional IT (e.g. servers, routers, data storage, copiers)	4	3d
0308	Cathode Ray Tube Monitors	2	3a
0309	Flat Display Panel Monitors (LCD, LED)	2	3b
0401	Small Consumer Electronics (e.g. headphones, remote controls)	5	4c
0402	Portable Audio & Video (e.g. MP3, e-readers, car navigation)	5	4c
0403	Music Instruments, Radio, HiFi (incl. audio sets)	5	4c
0404	Video (e.g. Video recorders, DVD, Blue Ray, set-top boxes) and projectors	5	4c
0405	Speakers	5	4c
0406	Cameras (e.g. camcorders, photo & digital still cameras)	5	4c
0407	Cathode Ray Tube TVs	2	4a
0408	Flat Display Panel TVs (LCD, LED, Plasma)	2	4b
0501	Lamps (e.g. pocket, Christmas excl. LED & incandescent)	3	5b
0502	Compact Fluorescent Lamps (incl. retrofit & non-retrofit)	3	5b
0503	Straight Tube Fluorescent Lamps	3	5b
0504	Special Lamps (e.g. professional mercury, high & low pressure sodium)	3	5c
0505	LED Lamps (incl. retrofit LED lamps & household LED luminaires)	3	5b
0506	Household Luminaires (incl. household incandescent fittings)	5	5a
0507	Professional Luminaires (offices, public space, industry)	5	5a
0601	Household Tools (e.g. drills, saws, high pressure cleaners, lawn mowers)	5	6
0602	Professional Tools (e.g. for welding, soldering, milling)	4	6
0701	Toys (e.g. car racing sets, electric trains, music toys, biking computers)	5	7
0702	Game Consoles	6	7
0703	Leisure (e.g. large exercise, sports equipment)	4	7
0801	Household Medical (e.g. thermometers, blood pressure meters)	5	8
0802	Professional Medical (e.g. hospital, dentist, diagnostics)	4	8

0901	Household Monitoring & Control (alarm, heat, smoke, excl. screens)	5	9
0902	Professional Monitoring & Control (e.g. laboratory, control panels)	4	9
1001	Non-Cooled Dispensers (e.g. for vending, hot drinks, tickets, money)	4	10b
1002	Cooled Dispensers (e.g. for vending, cold drinks)	1	10a

Appendix D: Trade data

Table D.1 Export of e-waste and used EEE from the Netherlands, in 2018 (in kt)

			EU	*At least going to*	non-EU							Unknown
		Total	Total	*Eastern EU*	Total	*Western Africa*	*Eastern Africa*	*Northern Africa*	*Western Asia*	*Eastern Asia*	*Southeast Asia*	Total
Legal e-waste	Total	19	19		0.0011							
Illegal e-waste	Total	12–20										12–20
Used EEE	Total	30.9	15.6	7.5	10.7	*7.8*	*0.2*	*0.2*	*1.1*	*0.7*	*0.6*	4.6
	TEE	6.4	0.4	0.4	3.1	*2.7*	*0*	*0*	*0.2*	*0*	*0.1*	2.9
	Screens	5.5	1.7	1.7	2.8	*2.7*	*0.1*	*0.1*	*0*	*0*	*0*	1.0
	Lamps	0										
	Large Equipment	6.8	5.4	0.6	1.7	*0.9*	*0*	*0*	*0.4*	*0.2*	*0.2*	-0.3^
	Small Equipment	4.6	3.2	3.0	1.6	*0.8*	*0*	*0*	*0.2*	*0.1*	*0.2*	-0.2^
	Small IT	7.6	4.9	1.7	1.5	*0.7*	*0.1*	*0.1*	*0.3*	*0.4*	*0*	1.3

^ The traded volumes per region are based on mass balancing procedures from different data sources. ‘Unknown’ is calculated as the difference between total export and the sum of known imports. Figures, therefore, not always add up to the total.

Appendix E: Chemicals in EEE and related health risks

Table E.1: Uses and regulations regarding chemicals in EEE and their related health risks

Chemical	Health risks [5]	Use and most important regulations
Polychlorinated dibenzo-p-dioxins and Furans (PCDD/Fs)	Persistent and bio-accumulative substances, possibly carcinogenic, causing immune and enzyme disorders and chloracne; Furans have also been detected in breast-fed infants.	Not produced intentionally, generated as unwanted substances in the incineration of waste and e-waste, especially of cables with PVC insulation (Zhang et al., 2015) and copper catalysts (Energy Justice Network, 2003). PCDDs/Fs can also be generated during chemical synthesis processes as a contaminant, listed as POPs under the Stockholm Convention (UNEP, Stockholm Convention).
Polybrominated diphenyl ethers (PBDEs) [1]	Persistent and bio-accumulative substances, impact on thyroid function and reproductive health, and causes endocrine disruption.	Group of brominated flame retardants with high potential to form dioxins and Furans (PCDDs/Fs) in incineration processes, in particular in the presence of copper (c.f. above). Together with PBBs, another group of brominated flame retardants, restricted under EEE in Directive 2011/65/EU since 2006; listed as POPs under the Stockholm Convention.
Polycyclic Aromatic Hydrocarbons PAHs	Certain PAHs are carcinogenic or cause various other health effects.	Naphthalene is produced intentionally, other PAHs occur naturally in coal, crude oil, and petrol, and/or result from the incineration of coal, oil, natural gas, wood, household waste, and tobacco. PAHs generated from these sources can bind to or form small particles in the air (CDC, 2009) and (Mumtaz and George, 1995).
Perfluorooctanoic acid (PFOA) [2]	Reproductive health, thyroid diseases, persistent and bio-accumulative.	Used on surfaces to repel water, oils and dirt, applied in textiles, certain types of paper and fire-extinguishing foams; contained in certain home products (e.g. carpets), main exposure from the intake of food and water that contains these chemicals (ECHA, 2018); use restricted under EU Regulation EC No. 1907/2006 (REACH); listed as POP under the Stockholm Convention (UNEP, Stockholm Convention).

Chemical	Health risks [5]	Use and most important regulations
Polychlorinated Biphenyls (PCBs) [3]	Persistent, bio-accumulative substance; endocrine disruptor, affects thyroid function; broad range of other health damages.	No known natural sources, use restricted, may still be contained in very old fluorescent lighting fixtures, larger capacitors of EEE, old microscopes, hydraulic oils and large power transformers (ATSDR, 2011); listed as POP under the Stockholm Convention (UNEP, Stockholm Convention).
Hexavalent Chromium	Carcinogenic, impacts reproductive health, causes ulcers.	Used as protective plating on metallic surfaces of products (ATSDR, 2012a); restricted under the RoHS Directive.
Manganese	In very high doses, adverse impacts on the nervous system (slow and clumsy movements), and irritation of the lungs, loss of libido, sperm damage.	Micronutrients, occurs naturally, used in steel, intake with food, fireworks, dry-cell batteries, fertilizers, paints, cosmetics (ATSDR, 2012b).
Nickel	Allergic contact dermatitis; nickel compounds are carcinogenic (lungs, nasal cavity), but cannot be clearly traced back to specific compounds; metallic nickel is probably not carcinogenic, exposure to the carcinogenic forms of nickel causes cancer outside the lungs and the nasal cavity.	Used in nickel plating, certain batteries, in many EEE components as a thin layer to prevent diffusion of metals in multilayer metallisations (ATSDR, 2005), (Barceloux and Barceloux, 1999) and (Hare, 2017).
Lead	Probably carcinogenic, affects the nervous system, causes motoric weaknesses, delays nerve development in children, causes kidney damage, anaemia, miscarriage, disturbs sperm production, and may cause death.	Batteries, ammunition, metal products (solder and pipes), X-ray shielding (ATSDR, 2007); most uses are restricted, e.g. under EU REACH Regulation and the RoHS Directive, still used in metal alloys and in ceramics in EEE due to exemptions (c.f. exemptions Annex III of RoHS Directive, Directive 2011/65/EU); also used in electronics in vehicles due to exemptions, despite of a general ban (c.f. Annex II of ELV Directive, Directive 2000/53/EC).
Cadmium	Long-term intake at lower levels (e.g. in food) may damage kidneys; long-term low-level exposure may cause bone fragility;	Most uses legally restricted, still found in old paints/pigments, NiCd batteries, plastics (ATSDR, 2012c); the use on electrical contact surfaces in switches of EEE is ongoing, despite increasing restrictions (RoHS

Chemical	Health risks [5]	Use and most important regulations
	carcinogenic (ATSDR, 2012c; Aoshima, 2012).	Directive exemption 8 of Annex III, Directive 2011/65/EU).
Arsenic	Carcinogenic; large oral doses of inorganic arsenic are lethal, lower levels of swallowed inorganic arsenic cause stomach and intestinal irritation, decrease the production of red and white blood cells, causing fatigue, abnormal heart rhythm, blood-vessel damage (bruising), impaired nerve function causing ‘pins and needles’ sensation in hands and feet. Long-term oral exposure may cause skin changes and skin cancer, swallowed arsenic causes cancer of the liver, bladder, and lungs. Inhaled inorganic arsenic likely to cause a sore throat and irritated lungs, skin effects, long-term exposure also causes circulatory and peripheral nervous disorders, and may affect foetal development (ATSDR, 2007b)	May be used in thick and thin film components similar to Cr and Mn.
Copper	Essential micronutrient; exposure to higher doses can be harmful. Long-term exposure to copper dust can irritate nose, mouth and eyes, cause headaches, dizziness, nausea and diarrhoea. Higher than normal levels of copper in drinking water may cause nausea, vomiting, stomach cramps, or diarrhoea. Intentionally	On printed circuit boards, components and cables of EEE; further uses in plumbing pipes, sheet metal, alloys to make brass and bronze pipes and faucets (ATSDR, 2004).

Chemical	Health risks [5]	Use and most important regulations
	high intakes of copper can cause liver and kidney damage and even death (ATSDR, 2004).	
Mercury [4]	Possibly carcinogenic; long-term exposition and/or higher doses of organic compounds and metallic mercury causes permanent kidney and brain damage, resulting in serious impact on the nervous symptom, such as personality changes (irritability, shyness, nervousness), tremors, changes in vision (constricting or narrowing the visual field), deafness, muscle incoordination, loss of sensation, and memory loss. Short-term exposure (hours) to high levels or long-term exposition to lower levels of metallic mercury vapour can damage lining of the mouth and irritate lungs and airways, causing tightness of the chest, a burning sensation in the lungs, and coughing. Other effects from exposure to mercury vapour include nausea, vomiting, diarrhoea, increases in blood pressure or heart rate, skin rashes, and eye irritation. Inorganic mercury can damage stomach and intestines,	Most uses are restricted (internationally under the Minamata Convention); in EEE still used in fluorescent lamps due to exemptions under the RoHS Directive (c.f. Annex III of Directive 2011/65/EU); may also be contained in electrical switches (Government of Canada, 2010) used in EEE and vehicles; the EU RoHS and ELV Directives restrict the use of mercury in such switches.

Chemical	Health risks [5]	Use and most important regulations
	producing symptoms of nausea, diarrhoea, or severe ulcers if swallowed in large amounts. Effects on the heart have also been observed in children having accidentally swallowed mercuric chloride. Symptoms included rapid heart rate and increased blood pressure.	

[1] banned in RoHS Directive; [2] restricted under REACH; [3] restricted under PoP regulation; [4] restricted in RoHS Directive; [5] based on Ohajinwa et al. (2019) and Awasthi and Li (2017).