



Report

Phasing out plastics

The electrical and electronic equipment sector

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Acronyms and abbreviations

ABS	acrylonitrile butadiene styrene
BAU	business as usual
BFR	brominated flame retardant
CPU	central processing unit
CRT	cathode-ray tube
DaaS	device-as-a-service
EEE	electrical and electronic equipment
EPR	extended producer responsibility
GESP	Global E-waste Statistics Partnership
GHG	greenhouse gas
GPS	Global Positioning System
HDPE	high-density polyethylene
HVAC	heating, ventilation and air conditioning
ICT	information and communications technology
ISWA	International Solid Waste Association
IT	information technology
ITU	International Telecommunication Union
LCI	Life Cycle Inventory
LDPE	low-density polyethylene
LED	low energy demand
LLDPE	linear low-density polyethylene
MFA	material flow analysis
NGO	non-governmental organisation
PET	polyethylene terephthalate
PMMA	polymethyl methacrylate
PP	polypropylene
ppm	parts per million
PS	polystyrene
PUR	polyurethane
PVC	polyvinyl chloride
RoHS	restriction of hazardous substances
StEP	Solving the E-waste Problem
UNU	United Nations University
WEEE	waste electronic and electrical equipment

Executive summary

Background

Today, almost all plastics are made from fossil-fuel raw materials (oil, gas and coal) and use fossil-fuel energy in their manufacture. Globally, they were the source of about 4% of greenhouse gas (GHG) emissions in 2015 (Zheng and Suh, 2019) – more than the whole continent of Africa. By 2050, on current trends, emissions from plastics will be three times present levels. Simply put, current trends for plastic production and use are incompatible with averting catastrophic climate change.

Analyses and campaigns on the negative side of plastics have focused predominantly on plastic waste, ocean pollution and threats to human health. The climate impacts of plastics must be filtered into this discourse to inform solutions to the various challenges posed by current plastic consumption. Tackling these challenges separately will not suffice. Better materials handling and waste management may help with pollution and waste, but will not address plastic's climate footprint. Similarly, the substitution of plastics derived from fossil fuels with ones from carbon-neutral sources will still cause waste and pollution. To have any chance of managing these challenges, we must downscale the problem. It is imperative from a climate and broader environmental perspective that we curtail the consumption of new plastic materials.

Context

This technical analysis is part of a broader research project investigating the technical potential for phasing out virgin plastic materials

produced from fossil fuels by 2050. Unlike most top-down and circular-economy analyses, we take a bottom-up approach to assess the use of six main ('bulk') plastics¹ in four sectors – packaging, construction, automotive and electrical and electronic appliances. These sectors together accounted for around 60% of plastics consumption in 2015, while the six bulk plastics accounted for 80% of all plastics production (Geyer et al., 2017).

These sector studies illustrate both the technical and high-level political feasibility of phasing out fossil plastics production and use in these sectors. They do not assess the likelihood of it being achieved, nor explore in detail the economic, political and behavioural dimensions of these changes.

Method

Our analysis uses current trends to forecast business-as-usual (BAU) demand for plastics in the sector in 2050. We then investigate the different uses of each bulk plastic type in the sector today to provide a basis for reducing future consumption in a low-plastics-consumption scenario. We estimate the technical potential to reduce the use of new plastic materials compared with BAU in 2050 by considering the potential for dematerialisation and reuse (avoiding the need for new plastic demand) and substitution (shifting the demand for new plastics to demand for other materials). The implications of this reduction and the opportunities to manage residual plastic production (for example, by using recycled plastics) are covered holistically in the companion synthesis report.

1 Polyvinyl chloride (PVC), polyethylene (PE), polyurethane (PUR), polystyrene (PS), polypropylene (PP) and polyethylene terephthalate (PET).

Plastics in electrical and electronic equipment today

The electrical and electronic equipment (EEE) sector consumes the least amount of virgin plastic materials of the four sectors analysed in this wider study, but was still responsible for 18 million tonnes (Mt) of plastic demand in 2015, having grown 3.8% a year over the two previous decades (Geyer et al., 2017). The concomitant development of the plastics and EEE sectors has inevitably seen them intertwine; many products in the EEE sector only became widespread once certain plastics were available. Plastics have often been the first-choice material for EEE components, as they can meet product specifications at a lower production cost than other materials. This has helped drive their growth and probably made these products available to lower-income consumers. Despite their near ubiquity in the EEE sector, few plastics play an intrinsic role in the operation of EEE and are, instead, often used for functions that are essential, but not plastics-specific, such as structural support and protective casings.

Two notable aspects of the distribution of plastics used in the EEE sector are that (1) the sector has the lowest proportion of total plastic consumption of the six bulk plastics analysed in this series (54%) (Geyer et al., 2017); and (2) none of the many EEE subsectors dominates the sector's plastic use. Plastic components and subcomponents are found in a very wide array of electrical appliances – from vacuum cleaners to air conditioning units and washing machines – and electronic devices (or electronics) – such as mobile phones, computers and televisions. The divide between electrical appliances and electronic devices is also often blurred, with many companies producing both.

Estimated average lifespans for plastics in the EEE sector vary from 2 to 17 years depending on the application. The disposal of waste EEE (WEEE) products has been a focus of environmental campaigners and legislators for decades. A limited quantity of plastics is recycled as part of broader WEEE recycling efforts, but plastics are not the primary target of these actions. Many EEE producers already employ recycled plastic in their products, driven in part by economics (recycled plastic may be cheaper

than virgin plastic) and in part by regulation. The degree to which plastic is recycled back to a similar use rather than downcycled to uses with less stringent specifications is unknown. In some cases recycling is constrained, because additives to plastics in previous uses are now known to be toxic and their levels in recycled plastic are legally controlled.

It is unlikely that facilities for plastics production will be specially designed or designated for the EEE sector alone. Rather, generic, unconverted plastic materials (resins) can be transformed into EEE components by myriad companies at various points along the supply chain. Larger and heavier electrical appliances are likely to be produced domestically, or at least within the same regional markets as the final products, while smaller and lighter electronic devices are more commonly produced in a few Asian countries, then transported internationally.

Opportunities to reduce demand in 2050

Our low-plastics-consumption scenario illustrates how the consumption of plastic materials could be drastically reduced in 2050 compared with a BAU scenario. It builds on projections set out in Grubler et al.'s (2018) low energy demand (LED) scenario, which makes substantial progress towards the Sustainable Development Goals – especially those related to poverty (SDG 1), hunger (SDG 2), health (SDG 3), clean energy (SDG 7), responsible consumption and production (SDG 12) and climate change (SDG 13).

Our 2050 low-plastics-consumption vision projects an increase in demand for EEE services, stemming from the faster growth in prosperity of the Global South assumed in the LED scenario. At the same time, however, we see this demand being met with fewer, more durable, multifunctional EEE products. Together, these factors yield a 12% decrease in demand for plastic materials compared with BAU.

The remainder of the reduction in plastics consumption considered in this report arises from a reduction in the intensity of plastic use in the EEE sector. This can be achieved by less material-intensive service delivery, especially by reducing overdesign and redundancy, and by substituting plastic materials with non-plastic alternatives. For

the bulk plastics considered in this analysis, most have structural and aesthetic roles that are already being filled by other materials in EEE products available today, plainly demonstrating that it is technically possible to significantly reduce the use of plastic materials by 2050. We project plastics consumption to be 56% lower than BAU in 2050 and 25% higher than in 2015.

The synthesis report to accompany this study considers the potential for satisfying this residual demand with plastics from recycled and non-fossil feedstock.

The combined reduction in plastic consumption could lead to a significant drop in GHG emissions from plastics production and use (45 Mt CO₂e in 2050, compared with 88 Mt CO₂e in 2015). However, the net effect on emissions will depend on the carbon intensity of any materials used to substitute plastics in 2050. Similarly, understanding the impact on broader environmental aspects would require more detailed case-by-case analysis.

Prevailing trends

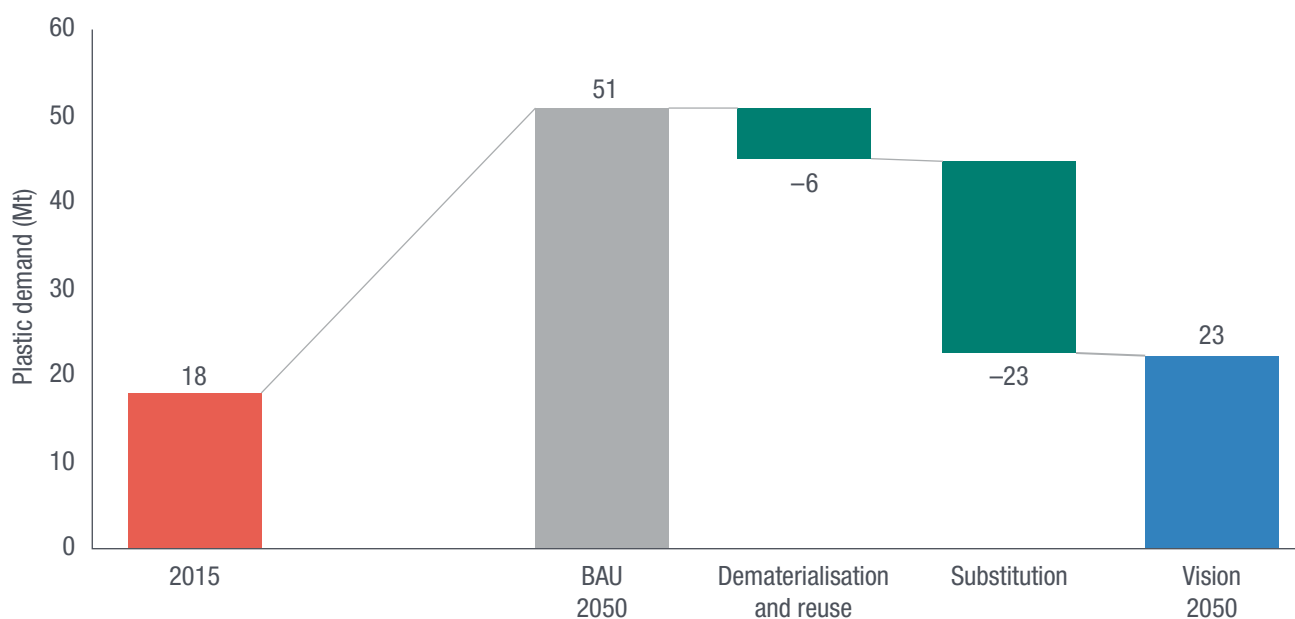
Plastic consumption by the EEE sector is rising, mainly driven by growth in the sector itself. Even though material prices are only a small determinant of the overall price paid by

consumers, the relatively low costs associated with producing plastic components suggests that plastics are likely to remain a key material for EEE producers unless there is a substantial shift in consumer preferences or regulation. Demand for low-cost EEE seems set to grow, especially in poorer countries. This is likely to be at the expense of more durable or repairable EEE, which may have higher upfront costs.

In many countries, the reuse, reconditioning and repair of EEE are already common and markets are well-established. Trade-ins and producer take-back schemes help to create reuse cycles, with some EEE products typically owned by a number of consumers over their lifetimes. A reduction in new demand would be complemented by the increasing design and manufacture of modular products that are easier to repair.

The pervasiveness of the sharing economy and the ready availability of products as a service (PaaS) – those that are rented rather than owned – would support the drive towards more durability. At the same time, there is some evidence to suggest that consumers will increasingly be able to do more with fewer, multifunctional devices. The impact of these trends is likely to be compounded by the continued shift towards cloud-based storage systems and some of the broader trends

Figure 1 Summary of potential for reducing plastics demand in the electrical and electronic equipment sector in 2050



Sources: Authors; Geyer et al. (2017)

envisaged by the LED scenario (such as urban densification), which we discuss in the other sector reports.

Recycling of WEEE is already a major priority for many nations. This will continue, as EEE products typically have easily identifiable producers, contain valuable materials, which are also sought by recyclers, and are themselves valuable, making them less likely to be simply discarded. Producers around the world are also moving to phase out toxic additives that have hampered the recycling of WEEE plastics in the past. Many have already begun to set goals to reduce the amount of virgin plastics used in their products.

Pathways to reducing demand

Our vision for 2050 involves broad global access to the beneficial services that EEE provides. Instead of constraining service demand, we focus on how these services may be provided with a much lower material (and, in particular, plastic) footprint. Fundamentally, this involves shifting away from inappropriate, short-lived, single-user EEE towards an EEE sector comprising appropriate, durable, shared and multifunctional

devices. This will require EEE products to be designed to be repairable, along with a massive rebalancing of markets towards those that prioritise direct reselling and reconditioning of EEE. A reduction in the number of EEE devices also requires amplification of PaaS business models in some sectors.

The visibility of EEE products, the emergence of a wider sustainability agenda led by environmentalists and key actors within the industry, and the growing number of rental and service business models suggest the potential to realise this reduction in plastic demand. However, the key to achieving our 2050 scenario is designing markets that favour durable, repairable and resaleable EEE products, as opposed to low-cost, single-user products. Voluntary and mandatory standards that promote durability, reparability and recycling, directly comparable lifecycle data and an increased focus on plastics specifically could help shape markets in a more sustainable way and reduce plastic demand. Although there is already action on some of these issues, the challenge will be scaling up these efforts, especially in parts of the world where EEE demand is forecast to grow most rapidly.

1 Introduction

1.1 Background

Today, almost all plastics are made from fossil-fuel raw materials (oil, gas and coal) and use fossil-fuel energy in their manufacture. They account for 9% of total demand for oil and 3% of total demand for gas and, by 2050, they could account for as much as 20% of oil demand (World Economic Forum et al., 2016). Plastics are also problematic for the global climate emergency. They were the source of about 4% of global GHG emissions in 2015 (Zheng and Suh, 2019) – more than all of Africa. By 2050, on current trends, emissions from plastics will be three times greater than present levels. However, global GHG emissions need to reach net zero by 2050 if the world is to have a chance of averting catastrophic climate change (IPCC, 2018).

Recently, plastic waste and pollution have been the dominant narrative on the negative side of plastics. In addition to the effects of plastic pollution on sea life, concerns have arisen about toxicity and health problems related to plastic microfibres found in the air, water and food. Better materials handling and waste management will not be enough to address these challenges. Nor will they be resolved by substituting plastics derived from fossil fuels with those made from biomass – these will also lead to waste and pollution. It is imperative from a climate and broader environmental perspective that the demand for new plastic materials be curtailed.

1.2 Context

This technical analysis serves as part of a broader research project investigating the technical potential for the phase-out of virgin plastic materials produced from fossil fuels by 2050. Our focus complements existing

forecasting and circular-economy analysis, but our method is different. We take a bottom-up approach to assessing the use of plastics in four sectors (packaging, construction, automotive and electrical and electronic appliances), which together account for around 60% of total plastics consumption (Geyer et al., 2017). Our analysis focuses on the six main types of plastic (polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polyurethane (PUR)). These ‘bulk plastics’ accounted for about 80% of total plastics production in 2015 (Geyer et al., 2017).

We consider the upstream and downstream aspects of the plastic value chain to operate outside the individual sectors. In other words, the production of plastic pellets and the collection of waste plastic materials is largely separate to – and cuts across – the sectors in which plastic products are used. We therefore discuss opportunities to reduce the environmental impacts of plastics demand through changes to the production, recycling and disposal processes in the accompanying synthesis report. The technical reports in this study series focus on minimising the demand for plastic materials, because any reductions in aggregate demand facilitate easier management of these associated processes.

The purpose of these detailed sector studies is to illustrate both the technical and high-level political feasibility of phasing out fossil plastics production and use in these sectors. The target audience for the synthesis report is broad, including policy-makers, advocacy groups, the private sector and other researchers. The audience for the technical reports is narrower, primarily researchers and those working directly in the sector.

1.3 Methodology

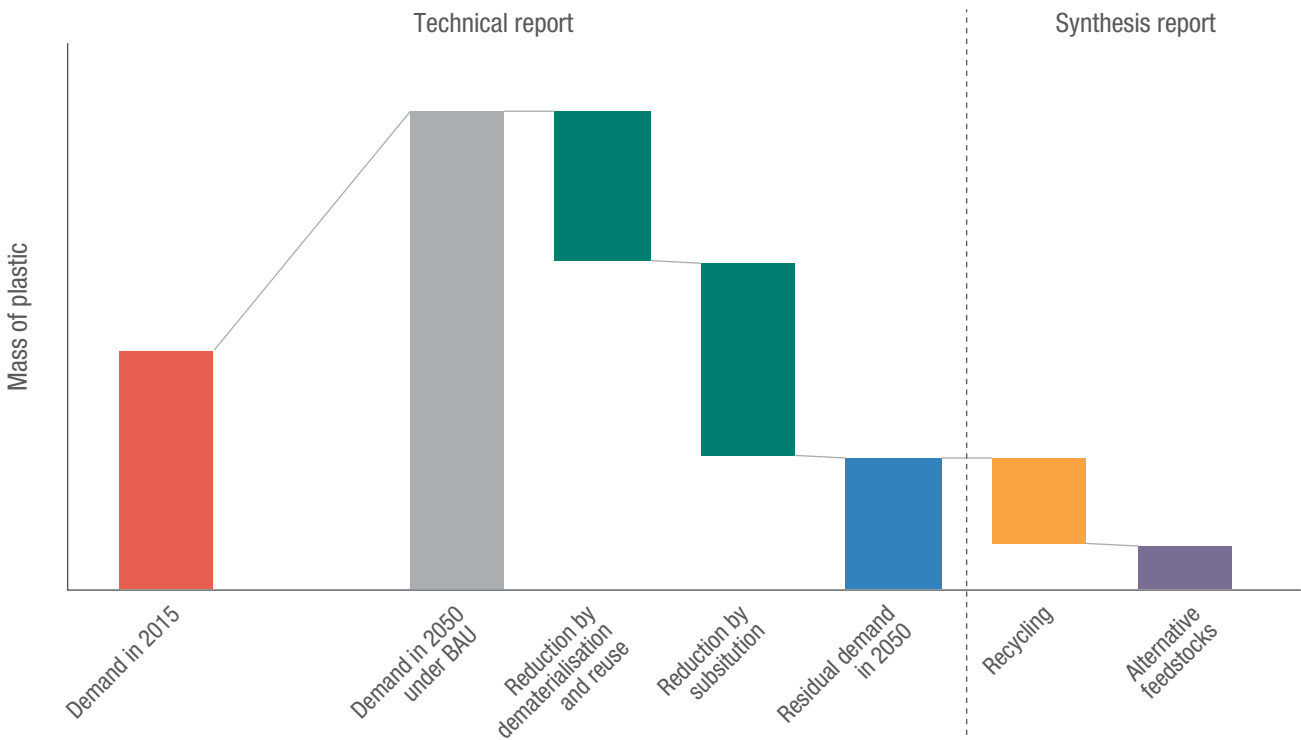
Our analysis begins by identifying the amount of plastic used in the EEE sector currently, and uses recent trends to project BAU demand for plastics in the sector in 2050. We investigate the different uses of each bulk plastic type in the EEE sector today to establish a basis for reducing future demand. We then calculate the technical potential to reduce the demand for new plastic materials compared with BAU in 2050 by considering the following opportunities in cascading fashion:

1. dematerialisation and reuse (avoiding the need for new plastic demand)
2. substitution (shifting demand for new plastics to demand for other materials)
3. plastics recycling (optimising waste management schemes associated with plastics)
4. non-fossil feedstocks (for residual demand that cannot be reduced by the above approaches).

This report focuses on the first two steps, namely, how to reduce demand. Steps 3 and 4 (how to accommodate residual demand) are addressed holistically for all sectors in the companion synthesis report. Figure 2 illustrates the process across the technical and synthesis reports.

We round out our focus on the technological feasibility of making changes by 2050 with some high-level insights into the political economy of bringing about such a transition – the interests, incentives and policies that influence key sector stakeholders and how these would need to change. However, the study does not assess the likelihood of the vision being achieved, nor explore in detail the economic, political or behavioural dimensions of these changes. Rather, we aim to present one possible outcome and illustrate how it might come about, rather than predict the future.

Figure 2 How to cut demand for fossil-fuel plastics in 2050



1.4 Structure of the report

The remainder of the report is structured as follows:

- Chapter 2 provides an overview of plastic consumption by the sector.
- Chapter 3 details the uses of plastics in the sector.
- Chapter 4 illustrates our 2050 vision for reducing the demand for virgin fossil plastics.
- Chapter 5 provides a high-level analysis of steps to achieve this vision.
- Chapter 6 illustrates the potential outcomes in 2050, illustrating total demand for plastics in the sector under the low-plastics-demand scenario, the associated impact on CO₂ emissions and the amount of waste generated.
- Chapter 7 provides an overall conclusion to our analysis of the sector.

2 Plastics in the electrical and electronic equipment sector

2.1 Main plastic types, uses and trends

Plastic components are ubiquitous in the EEE sector, which was responsible for approximately 18 Mt (5% of total) plastics consumption in 2015 (Geyer et al., 2017). The use of plastics by the sector grew by 3.8% per year over the preceding two decades – the lowest rate of the sectors analysed (Geyer et al., 2017). Both industry associations (such as Plastics Europe, n.d.) and academics (for example, Gu et al., 2016) note that plastics are important elements in the EEE sector, which plays an incredibly useful role in daily life. Plastic components and subcomponents are found in a wide array of electrical appliances – from vacuum cleaners to air conditioning units and washing machines – and electronic devices (or electronics) – such as cell phones, computers and televisions.

The EEE sector is not consistently defined, hampering attempts to comprehensively establish which companies dominate the market and how large it is,² especially as the divide between electrical appliances and electronic devices is often blurred, with many companies producing both (LG, for instance, makes both washing machines and cell phones). Even so, Wath et al. (2010) labelled the electronics sector as the world's largest and fastest-growing manufacturing industry.

The concomitant development of the plastics and EEE sectors has led them to intertwine, perhaps more than any other sector analysed in this report series. While the automotive and construction sectors were well-established before plastics were a dominant material (the growth of plastics in these industries largely being due to plastics replacing other materials), many products in the EEE sector only became widespread when plastics were available. Plastics have often been the first-choice material for EEE components. This is in part because the relative ease with which plastics can be handled means manufacturers can reduce production costs compared with other materials, even when raw material costs are similar.

It is largely plastics' 'ability to effect weight and cost savings without compromising on aesthetics and functionality' that has led to their broad take up by the industry (Frost and Sullivan, 2019), rather than a direct consumer preference for plastics. These cheaper and lighter products have been key to the growth of the EEE market, with lower costs probably having expanded the availability of these products to lower-income consumers. For electronic devices in particular, this needs to be set against the fact that the cost of plastics is usually a minor part of overall production costs and just a fraction of the price at which products are sold (see, for example, Reisinger, 2016; Lembart, 2018).

2 For example, the Fortune Global 500 list of the highest revenue-generating companies lists Apple as part of the computer and office equipment industry, but Hon Hai Precision Industry (aka FoxConn, which makes all of Apple's products) and Samsung Electronics as part of the (separate) electronics industry.

Plastics' versatility and lower cost have enabled the development of the modern EEE sector. But this co-evolution of plastics and EEE is only part of the story. At a functional level, plastics' use in the sector can be broadly divided into technologically advanced engineering plastics that play an intrinsic role in operation of EEE and bulk plastics that are used for functions that are not plastics-specific, such as structural support and protective casings.

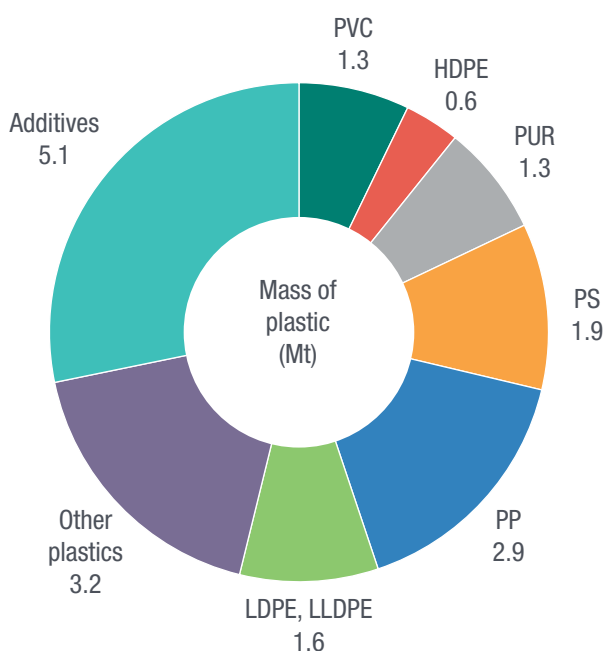
Figure 3 shows that bulk plastics (the focus of this report) accounted for 54% of plastics used in the sector in 2015. Additives, most of which are likely to be found with bulk rather than engineering plastics, are responsible for another 28% of plastics consumed by the sector. Most consumer electronics also use other plastics that are not included in this analysis, some in relatively large quantities.³ Many of these other plastics, such as polycarbonate, polymethyl methacrylate (PMMA) and acrylonitrile butadiene

styrene (ABS), appear to mainly be employed for structural and protective uses (for example, see OKW Enclosures, n.d.). This suggests that less than one-fifth of the plastics consumed by the electronics sector are high-end engineering plastics with intrinsic applications (printed circuit boards, for example, are usually made from FR4 – a fibreglass and epoxy resin composite, rather than one of the bulk plastics). Rather, the EEE industry tends to use plastics to provide structural support, protection for other components, aesthetic coverings or some combination thereof. None of the many subsectors in the EEE sector dominates plastic use; it is split over a large range of applications. This is exemplified by the fact that none of the 35 examples of bulk-plastic use cited by the European plastics industry trade body relates to the EEE sector (Plastics Europe, 2018).

2.2 Geographies and markets

The relatively small proportion of total plastic production attributed to the EEE sector makes it unlikely that plastic production facilities will be specially designed for or designated to the sector alone. Rather, the raw plastic materials (such as polymer resins) used by the sector are likely co-produced with larger volumes for other sectors. The manufacturing process that transforms resins into components used in EEE devices can be carried out by the company making the final product, or parts can be made by intermediate companies and then assembled. How companies lay out their supply chain can vary by size, product and component. For example, Samsung Electronics tends to buy in smaller components, but manufacture its own plastic parts for larger components using plastic resin purchased from a sister plastic-producing company, Samsung Total Petrochemicals Co., Ltd (Government of Canada, 2012). Smaller and lighter electronic devices may be transported internationally, while larger and heavier electrical appliances are likely to be produced domestically, or at least within the same region as the final product.

Figure 3 Electrical and electronic sector consumption of polymer resins globally in 2015



Note: LDPE, low-density polyethylene; HDPE, high-density polyethylene; LLDPE, linear low-density polyethylene.

Source: Geyer et al. (2017)

3 Market research into the consumer electronics market for plastics also details demand for polycarbonate, ABS, styrene-acrylonitrile resin (SAN), acrylonitrile styrene acrylester (ASA), PMMA and others (including styrene ethylene butadiene styrene (SEBS), polyphenylene ether (PPE), polyphenylene oxide (PPO), polyamide (PA) and plastic blends) (Transparency Market Research, n.d.).

Production of electronic devices is often considered to be dominated by a few Asian countries, most notably, China, South Korea, Taiwan, Japan and Viet Nam (Greenpeace, 2017). However, because many countries both directly re-export imported electronics and integrate imported components into other devices that are then exported, it is difficult to trace this in international trade statistics (Figure 4). In dollar terms, China, Hong Kong, the United States and Germany dominate the import and export of EEE.

2.3 Data limitations

The range of applications, appliances and markets and the paucity of data available from manufacturers frustrate attempts to comprehensively describe the amount of and reasons for plastics use in the sector. The reasons for the limited data availability on plastics use are (1) their relatively small value or impact compared with other materials/components; and (2) commercial confidentiality. A review of the lifecycle impacts of changes in the design of refrigerators by the Japan Electrical Manufacturers' Association (2014), for example, provides an aggregate value for the mass of

plastics used (around 40% of the total), but does not specify what the 15 plastics included in this total are used for. Similarly, Fairphone – arguably the most sustainably minded electronics company in the world – has redacted the inventory lists for its components from its published lifecycle assessment, which only looks at the end-of-life fate of the battery and metals (Proske et al., 2016). Other issues include the crossover between plastics used for EEE in the consumer and institutional products, automotive and construction sectors.

Most of the data on sectoral plastics use presented here is, therefore, taken from discussions of WEEE. This introduces a considerable time lag to the data. According to Geyer et al. (2017), 18 Mt of plastics were used by the electronics sector in 2015, yet the sector only produced two-thirds of this amount (13 Mt) in waste that year. The lag is compounded by the various in-use lifetimes of different plastic-containing products and the pace of change in some parts of the sector.

A final complication stems from the different product groupings adopted in different regions, which have also changed over time. In China and Japan, five electronics products have tended to be taken as representative of the broader industry (see, for example, Gu et al., 2016; Li et al., 2019; Yagai, n.d.): televisions (TVs), computers (PCs),

Figure 4 Import–export balance of electrical machinery, equipment and parts, 2018



Source: Intracen (2019)

Box 1 Waste electrical and electronic equipment classification in the EU

Temperature-exchange equipment. More commonly referred to as cooling and freezing equipment. Typical equipment includes refrigerators, freezers, air conditioners and heat pumps.

Screens. Typical equipment includes televisions, monitors, laptops, notebooks and tablets.

Lamps. Typical equipment includes fluorescent lamps, high-intensity discharge lamps and light-emitting diode lamps.

Large equipment. Typical equipment includes washing machines, tumble dryers, dishwashers, electric stoves, large printing machines, copying equipment and photovoltaic panels.

Small equipment. Typical equipment includes vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radios, video cameras, electrical and electronic toys, small electrical and electronic tools, small medical devices and small monitoring and control instruments.

Small IT. Typical equipment includes mobile phones, Global Positioning System (GPS) trackers, pocket calculators, routers, personal computers, printers and telephones.

Source: Adapted from Baldé et al. (2017)

Table 1 Approximate lifespans of selected common electrical and electronic equipment

EEE	Song and Li, 2015 (years)	Proske et al., 2016 (years)	Baldé et al., 2017 (years)	Fiore et al., 2019 (years)
Mobile phones	–	3	1.5–2	2–5
Personal computers and laptops	4–5	–	4	2–5
Televisions	8	–	9	5–7
Washing machines and dishwashers	10	–	12	10
Air conditioning units	10	–	17	10
Refrigerators	9	–	–	–

washing machines, air-conditioning units (AC) and refrigerators. Some 760 million of these items were produced in China in 2013 (Gu et al., 2016). The European Union (EU) originally classified WEEE into 10 groups (Martinho et al., 2012), but recently narrowed that down to six, as suggested by the Global E-Waste Monitor (a United Nations University (UNU) initiative) and set out in Box 1 (Baldé et al., 2017). In the United States, regulation of WEEE is mainly at state level, so the definitions of WEEE vary. A 2013 report by the Massachusetts Institute of Technology considered ‘electronics’ to include

just four product types (computers, monitors, TVs and cell phones) (Duan et al., 2013).

2.4 The lifespan of EEE plastics

Table 1 shows that the lifetimes of EEE plastics vary considerably across EEE subsectors. In general, there has been a decrease in average in-use time for EEE in recent decades, as technological development and marketing have combined to accelerate consumer desire for the latest versions of appliances and devices (Gu et al., 2016).

2.5 End-of-life treatment

WEEE typically includes the plastic components originally integrated into EEE products, and plastics are subject to most of the trends affecting WEEE more broadly. WEEE has received considerable attention from environmental campaigners, policy-makers and the waste industry in recent decades, mainly due to:

- worries about environmental damage (such as refrigerant gases and persistent organic pollutants)
- the potential for harm to human health (from heavy metals or brominated flame retardants (BFRs), for instance)
- the economic potential for recycling materials in WEEE (metals and glass, for example) (Fiore et al., 2019; Wang and Xu, 2014; Stenvall et al., 2013).

Until very recently, it was common practice for richer countries to export WEEE rather than recycle it domestically. This was driven by lower labour costs and less stringent environmental regulations in developing countries (Man et al., 2013). In the EEE sector, this gave producing countries a ready supply of recyclable material, often required in products manufactured for those wealthy markets.

In theory, WEEE is subject to the 2002 Basel Convention, effectively outlawing the export of polluting toxic materials (Ibanescu et al., 2018). However, environmental NGOs have shown how WEEE exports can end up being handled by the informal sector in developing countries, increasing the likelihood of unsafe recycling practices (Puckett et al., 2016; 2018; Gu et al., 2017) – ‘e-waste dumping’ (Vidal, 2013). More recent policy changes in response to this by WEEE-importing countries (most notably China’s National Sword Policy) have impacted the international movement of waste – both decreasing the aggregate amount of WEEE and diverting it to countries with less stringently enforced import policies. However, insufficient accounting mechanisms for internationally traded WEEE can make these flows difficult to track (Duan et al., 2013).

Where WEEE is treated, it is most likely to undergo mechanical recycling (Awasthi et al., 2018). This tends to involve manual dismantling (which is more efficient for separating components, especially metals) combined with a mechanical process (typically shredding and sorting based on material characteristics, such as density) (Ueberschaar et al., 2017). More complex devices (such as mobile phones) may just be chemically treated to recover the metals, with other materials (notably plastics) discarded or burned in incineration plants (see, for example, Proske et al., 2016).

Several countries and regions have implemented recycling targets. For example, EU Directive 2012/19/EU (EU, 2012) required 85% of the mass of WEEE generated to be recycled by 2019. As plastics typically constitute more than 15% of WEEE, this implied that at least some plastics must also be recycled (Stenvall et al., 2013). However, official data show this target is far from being realised, either in the EU (where an estimated 35% of WEEE is recycled) or globally, where the fate of the vast majority of WEEE (around 80%) is not documented (Baldé et al., 2017; Forti et al., 2020). It is possible that some of this waste plastic is recycled but not captured by official data, but the estimated value of materials lost from the formal economy via WEEE in 2016 was €55 billion (Baldé et al., 2017). Closing production loops in line with circular-economy principles would allow much of this value to be recovered. Although plastics usually account for a small part of the value of EEE products (especially electronics) in material terms, the loss of plastic resources may be more acute for countries without fossil-fuel production and processing infrastructure (Martinho et al., 2012).

The main reason that recycling rates are falling short of their targets is that there are often insufficient monetary incentives to recycle WEEE. In some jurisdictions, recycled plastics are cheaper than virgin materials, so are used in new EEE, but this plastic is often sourced from waste from other sectors rather than from WEEE. Fiore et al. (2019) draw together research by others that shows how these economic barriers are bolstered by several structural or systemic hurdles to a truly circular economy in the WEEE sector, including:

-
- WEEE management being dominated by the informal sector in many low- and middle-income countries, meaning compliance may be low even if specific regulations exist
 - the dominance of the informal sector, combined with poor infrastructure for the collection and separation of WEEE, which can lead to insufficient facilities and capacity for correct – and safe – WEEE processing
 - a lack of involvement and awareness of consumers and local authorities.

Another barrier limiting the recycling of plastics from WEEE stems from the EU Directive on the Restriction of the use of certain Hazardous Substances (RoHS) in EEE (Directive 2011/65/EU) (EU, 2011; Stenvall et al., 2013). The RoHS

mainly functions to limit the quantity of hazardous additives that are often present in components constructed from bulk plastics. Plastics containing any BFRs and heavy-metal concentrations over 1,000 parts per million (ppm) (100 ppm for cadmium) cannot be recycled. More recently, regulations have been considered for pro-oxidant additives (which may facilitate the degradation of recycled plastic materials) and phthalates (particularly those in PVC, which are known to be toxic) (Shawaphun et al., 2010; Pecht, 2018). Many plastics containing these additives can only be disposed of by incineration in cement kilns (in other words, not only can they not be recycled, but the products of their combustion are too toxic for them to be disposed of in standard incineration plants) (Martinho et al., 2012).

3 Plastic uses in electrical and electronic equipment

3.1 By plastic type

Table 2 provides an overview of some of the uses of various plastics in the EEE sector.

No data were available to comprehensively quantify plastic consumption by end use, and averaged values should be treated with caution given the variety of EEE products, markets, sectors and uses of plastic materials. Nonetheless, some studies have attempted to quantify some aspects of plastics use in EEE. In their analysis of the plastic profiles of more than 3,000 WEEE items, for example, Martinho et al. (2012) note that previous analyses suggest plastics accounted for 10–30% of all WEEE by mass. While others have reported findings within this range – for example, Wang et al. (2018) suggest from a review of available data that an average flat-panel television contains 5.7 kg of plastic (21% of its total mass), concurring with findings by Fiore et al. (2019) – it seems like an over-generalisation. For example, breaking their analysis down by category, Martinho et al. (2012) show that the mass of plastic ranges from 3.5% of the total for central processing units (CPUs) to 49.1% for small WEEE items, and that the total amount of plastic varies from less than 1 kg on average in small WEEE to 16 kg per photocopier (see Figure 5).

Similar outliers are readily available in sector-specific studies. For example, Li et al. (2019) report plastics to account for 30–44% of the total mass of a refrigerator, which chimes with the approximate 40% reported by the Japan Electrical Manufacturers' Association (2014). Some 50–60% plastic content has been observed

in vacuum cleaners (Gallego-Schmid et al., 2016) and just 7% in dishwashers and washing machines (Fiore et al., 2019).

This variation is probably the result of attempts to characterise such a broad range of products into relatively few categories. Plastic content can vary considerably from company to company and category to category: small

Table 2 Common uses of plastics used in electrical and electronic equipment

Plastic type		Example uses
PE		Cable and wire insulation, appliance housing
PP		Housings and handles for higher-temperature environments (such as kettles)
PS		Refrigerator trays/linings, TV cabinets
PUR		Insulation in fridges and freezers (thermosetting), appliance housing (thermoplastic)
PVC		Cable and wire insulation, cable trunking
Other	Structural/aesthetic: for example, polycarbonate, PMMA, ABS	Housings for telephones, music systems, computers, keyboards, monitors, toasters, coffee machines
	Technical: for example, alkyd, amino or epoxy resins	Circuit breakers, switchgear, light fittings, components, circuit boards

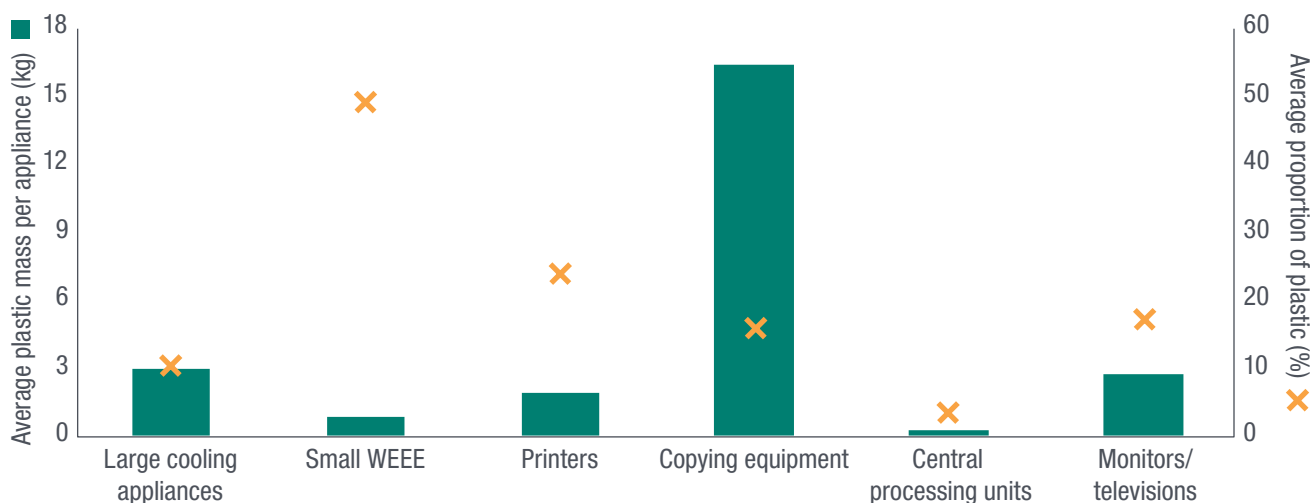
Source: British Plastics Foundation (n.d.)

IT items produced by Apple, for example, vary from 4–5% for a Mac Pro and iMac to 26% of the mass of a HomePod (see the environmental report cards at Apple, n.d.a).

In addition to total mass, the types of plastic used vary significantly between WEEE types. Martinho et al. (2012) found three-quarters of the plastic used in large cooling appliances to be PS. Perhaps illustrating the aesthetic, rather than functional, nature of plastic in EEE, Figure 6 shows that PS was also the dominant plastic used in cathode-ray tube (CRT) televisions (85%), but made up just 4% of the plastic used in CRT monitors. The only

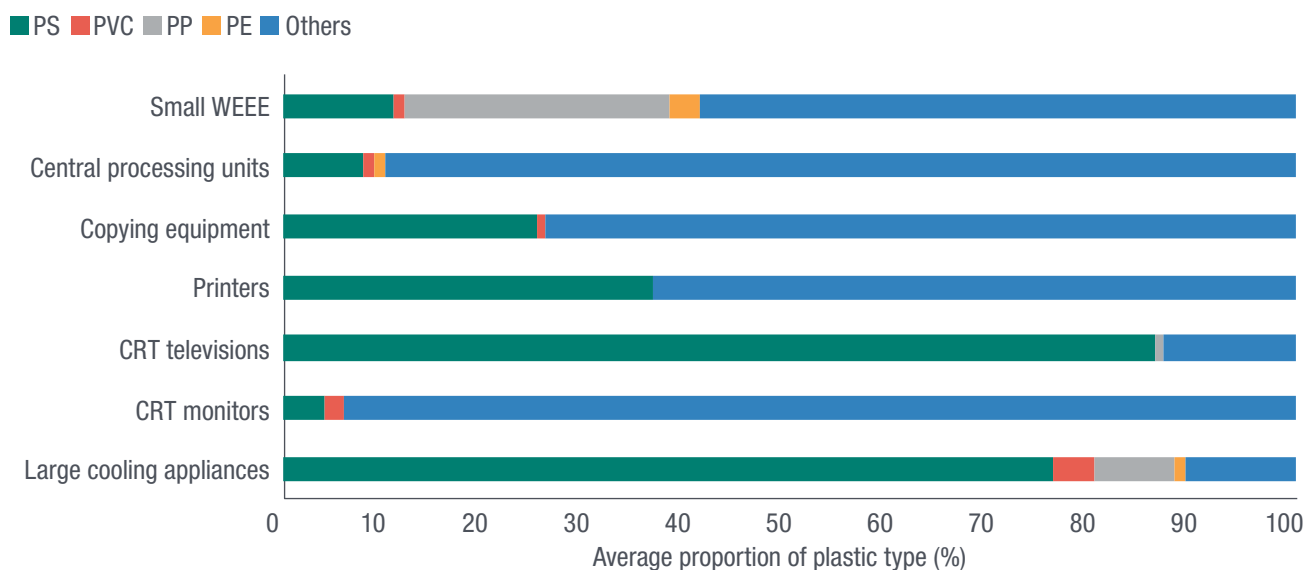
other plastic (within the focus of this analysis) that Martinho et al. found in any notable quantity was PP, in small WEEE devices (20% of total plastic), though some PP (8%) and PVC (4%) were also found in large cooling appliances. Underscoring the challenges of finding representative data, these figures are starkly different to those for vacuum cleaners (37% PP, 11% PVC, 8% HDPE, 44% other) and fridges/freezers, in which 47% of the plastic found was PUR (Fiore et al., 2019). It is difficult to reconcile these figures for individual uses with the global consumption figures presented by Geyer et al. (2017) (Figure 3).

Figure 5 Mass and proportion of plastics in common waste electrical and electronic equipment



Source: Martinho et al. (2012)

Figure 6 Average proportions of plastic types in common waste electrical and electronic equipment



Note: CRT, cathode-ray tube.
Source: Martinho et al. (2012)

4 Plastics in the electrical and electronic equipment sector in 2050

As outlined in chapter 1, our approach is to compare two possible 2050 scenarios: a BAU scenario and a low-plastic-consumption one. As discussed in more detail in the synthesis report, we approximate BAU as 3% growth per year. The low-plastic-consumption scenario is based on the 1.5°C-compatible LED scenario published by Grubler et al. (2018). The LED scenario is mainly focused on energy demand, so does not relate directly to all of the SDGs. However, energy use within the LED scenario surpasses the relevant Decent Living Standards (Rao and Min, 2017).⁴

The amount of plastic used by the EEE sector can be approximated by the sector's activity (the amount of new EEE devices) and its plastic intensity (the amount of new plastic in each new device). The LED scenario provides a framework to investigate changes in activity – the demand for the services that plastic materials provide compared with the BAU scenario – through dematerialisation and reuse. We augment this with an analysis of reductions in the sector's plastic intensity – the potential to fulfil residual demand for plastic materials with other materials – through substitution.

4.1 Vision 2050

The LED scenario projects that the number of electrical devices will more than double between now and 2050, to reach 134 billion appliances in

use, as global prosperity increases, especially in the Global South. This corresponds to an annual average growth rate of 3.5%, comprising 4.1% growth in the Global South and 2.6% in the Global North. This is higher than the 3% growth rate under our BAU scenario, mainly because the LED scenario projects substantial economic gains in low- and middle-income countries, increasing the number of people able to own EEE.

The higher growth rate results in approximately 18% more devices in 2050 than under our BAU. Even so, this figure is assumed to be considerably lower than it might otherwise be, as it includes three key emerging trends that reduce rates of individual device ownership:

- a shift away from private ownership towards appliances as a service, both for domestic (such as washing machines in multi-family buildings) and business purposes (for instance device-as-a-service (DaaS)) (see, for example, HP, 2019)
- the increased use of cloud computing and virtualisation (accessing hardware and digital content stored elsewhere, rather than locally)
- device consolidation, where multi-function appliances provide the services previously provided by many others.

The third trend builds on Grubler et al.'s (2018) illustration of how smartphones today already provide the services previously provided by 18

⁴ Specifically, in terms of shelter, consumer goods, mobility and nutrition. See Supplementary Note 12 in Grubler et al. (2018) for more.

individual devices and could include, for example, integrated home communication, entertainment and security systems, or wearable technology that integrates communication technology and health monitoring.

4.1.1 Impact on new EEE product sales

The turnover of products is affected by competing trends. The rise in the shared use of EEE would probably increase what might be termed their ‘load factor’, or the proportion of each day that they are in use. This could have little impact on demand for EEE that is currently replaced before the end of its useful life, but where the lifespan of EEE is mainly dependent on in-use time (because of wear and tear), the lifespan would decrease, as such EEE would wear more quickly. However, the same trend could also underpin the purchase of higher quality and more robust appliances, which, along with a modular design revolution that saw a return to products that could be easily disassembled and repaired, would extend their in-use lifetime and reduce demand for new products.

It is, however, unclear which of these trends would have the bigger effect, so we assume that average turnover rates are broadly similar to those

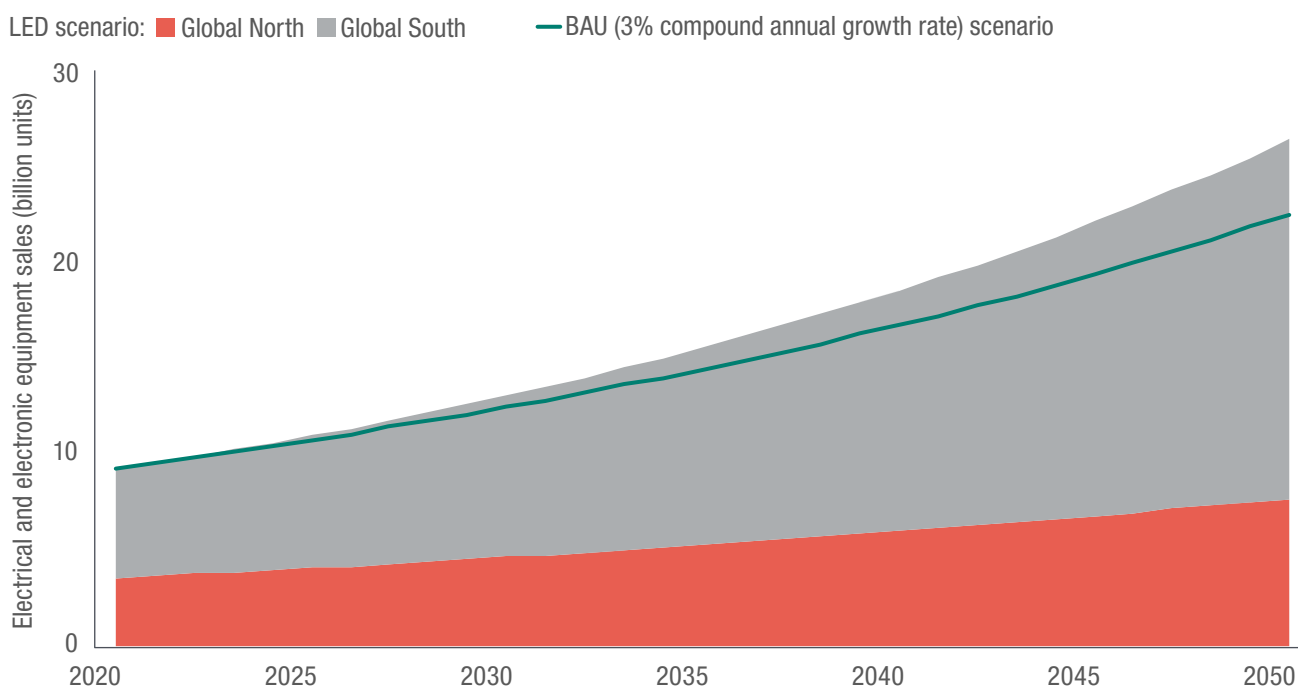
today. The compositional data for EEE in 2050 under the LED scenario (A. Grubler, pers. comm., 2019) and the average lifespans of different product groups in use today (Baldé et al., 2017) yielded a weighted average of approximately five years. For the scenarios described above, using projections from the LED scenario yielded a demand for approximately 26.8 billion new EEE products in 2050, compared with 22.8 billion under BAU (Figure 7).

4.1.2 Reuse and recycling of EEE in 2050

The advances in modular, repairable, durable designs would also facilitate far higher levels of reuse, thanks to better-developed resale markets (analogous to reuse in our model, see chapter 1). Based on the expected prevalence of information and communications technology (ICT) devices in total EEE in 2050 and the world-leading reuse rates in parts of the ICT sector today (see chapter 5), we estimate that 25% of global demand for EEE could be met by direct resale or reconditioning in 2050.

Recycling rates for the EEE sector in 2050 would be much higher than those today, as legal regulations around the world created business models that facilitated near-complete recycling of

Figure 7 Demand for electrical and electronic equipment under different scenarios



Source: Authors, based on data from Grubler et al. (2018)

WEEE. This would be driven in part by the growth of circular material economies more generally, and in part by growth in the importance of more localised, on-demand production (for example, additive manufacturing or 3D printing for spare parts). Product labelling, similar to that used for energy efficiency and recycling today (Figure 8), would detail the carbon footprint and material composition of each EEE device. This increase in visibility of the impact would allow sustainably minded consumers to make side-by-side comparisons of devices in markets that more fully reflected the full costs of ownership or usership (for example, resource taxes and a reuse/recycling levy could be factored into the retail price).

A major shift in residual plastic demand would arise from the sector’s step change in the use of recycled materials compared with the status quo. Much broader and well-funded extended producer responsibility (EPR) schemes would ensure far higher WEEE collection rates. Simplified EEE design, to create more easily disassembled devices and the prohibition of toxic, plastic-deteriorating and non-recyclable additives, would allow better-quality plastic waste to be

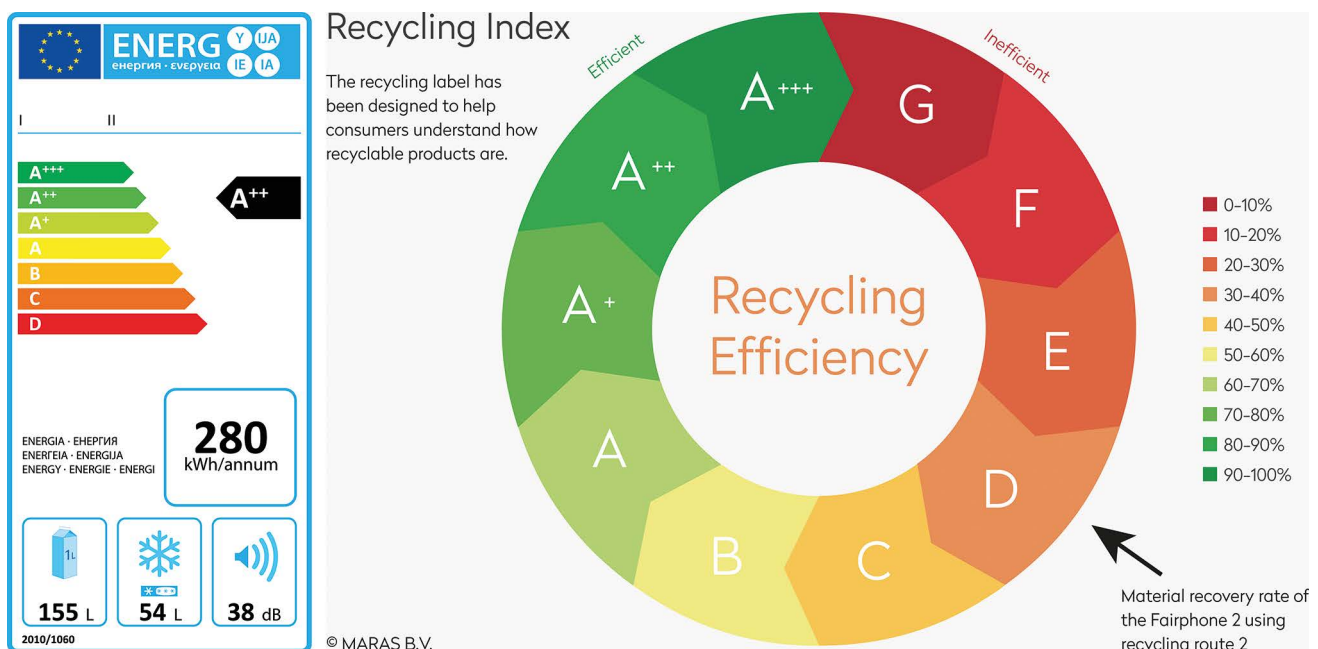
produced. Clear, ambitious and enforced WEEE directives would mean that the cost, effort and infrastructure required to recycle plastic WEEE would be shared over all EEE materials. New recycling routes, processes and benign/inert materials would overcome current concerns about the contamination of recycled plastic streams with additives and other plastics (such as biopolymers).

Moreover, recycling should be easier in the EEE sector than other sectors. EEE products are typically made by easily identifiable producers, contain valuable materials sought by recycling schemes and are themselves valuable, making them less likely to be discarded. Together, these factors could push plastics recycling in the EEE sector to the upper limit of that suggested by Material Economics (2018) (80%).⁵

4.1.3 High-level impacts on demand for plastics

The consumption of plastics by the EEE sector is a function of the demand for new EEE (activity, in terms of the number of new devices) and the plastic intensity of that activity (the amount of plastics used per device). We use these two

Figure 8 Examples of energy and recycling efficiency labelling



Source: Wikipedia images (2010); Fairphone (n.d.b)

⁵ This figure is just for information. Recycling rates are considered holistically across all sectors in the accompanying synthesis report.

aspects to frame our analysis of opportunities to reduce the consumption of new plastic materials by the EEE sector.

The combined impact of the low-plastics-consumption scenario and dematerialisation yields annual demand for EEE in 2050 that is 191% higher than 2015 levels⁶ (the latest available data on sectoral plastics consumption). Crudely, if the intensity of plastics use in 2015 continued out to 2050, this would result in an EEE sector that consumed 46 Mt of plastics in 2050. For comparison, our assumption of annual growth of 3% under a BAU scenario would result in plastics consumption of 51 Mt in 2050 (so, our low-plastics-consumption scenario shows a reduction of 12% in demand for plastic compared with BAU).⁷ Again, for comparison, the growth we assume under BAU is considerably lower than many other short-term market forecasts which, for example, project annual growth of 6.9% in plastics for the EEE industry (Grand View Research, 2017), itself projected to grow by more than 6% a year over the next five years (Globe Newswire, 2018).

In addition to these changes, the low-plastics-consumption scenario offers various ways in which the intensity of use by the EEE sector might be decreased, by reducing the amount of plastics required to satisfy demand (dematerialisation by use-efficiency) and substitution with other products, both of which we explore in the following section.

4.2 Alternative ways of meeting plastics demand in 2050

There is evidence to suggest that much of the remaining demand for plastics in the sector (88% of BAU) could be met using less plastic, or non-plastic alternatives. Sometimes these approaches cross over – that is, products that deliver the same service can require fewer materials and can incorporate alternatives to plastics.

One example of how the 2050 vision could lead to a further decrease in demand for plastics

for EEE relates to a shift towards smaller EEE products, especially for households. For example, the shift to more compact homes and offices, described in this study's construction-sector report, and the continued emergence of on-demand food delivery, as noted in the packaging-sector report, could steer consumer demand from larger to smaller refrigerators. In the UK, the total mass of current refrigerator models ranges from approximately 15 kg to 75 kg (see, for example, Currys PC World, n.d.a; n.d.b). No data were available on the variation of plastic content by size of refrigerator, but assuming this is similar for differently sized options, a shift in consumer demand towards the smaller end of the scale would yield a considerable reduction in the quantity of plastic required to provide the same service.

This shift to smaller EEE could also impact many other appliances and electronics, for example replacing wide-screen televisions, which typically weigh over 10 kg, with pocket-size projectors that already weigh as little as 0.25 kg (for example, see Hoffman, 2017) and replacing physical computer input devices with ones based on projected images or gestures.

Separately, there appear to be few technical barriers to substituting many plastics with other materials. This is already common in market segments with higher retail prices. The decision to substitute plastics can be for mainly aesthetic reasons to do with consumer taste – for example, brushed metal and wood are common casing alternatives – or functional reasons – various types of steel are used in many commercial EEE products, as it is considered to be easier to clean and more durable. In some cases, a reduction in demand for plastic materials may be an outcome of higher recyclability criteria, as already observed for stainless steel, for example (Bakhiyi et al., 2018). Additive manufacturing (of which 3D printing is a subset) is a well-established process that can create fully customised products from non-plastic materials, including metals, ceramics and biomass materials (Thompson

6 This forecast is compiled by backcasting the calculated 2020–2050 growth rates for the 2015–2020 period.

7 This includes the 18% increase compared with BAU from LED-scenario figures and the 25% reduction in demand owing to reuse (in other words, $118\% \times (100\% - 25\%)$).

et al., 2016). One particularly relevant sector is the growing opportunity presented by additive manufacturing's ability to directly create standalone and fully functional electromechanical parts (Deloitte, 2017). The market for additive manufacturing was worth more than \$7 billion in 2017 and while, thanks to their use in 3D printing, plastics are currently the most common material used, metal is currently the fastest-growing category (GE, 2018).

As in the packaging sector, the relatively high visibility of products in the EEE sector could continue to promote greater consideration of sustainability criteria by consumers, thus challenging the use of virgin fossil plastics.

4.2.1 Examples of products that could reduce plastic demand

The business case for reducing the amount of plastic used in EEE has not been explored by researchers, though it seems a plausible opportunity for cost reduction. The innumerable plastic-containing products in the EEE sector prevent a comprehensive analysis. Instead, Table 3 shows how reduced plastic consumption in a broad range of EEE products is already occurring in some (albeit fringe) markets. This reduction in plastic-using EEE can be the result of total or partial dematerialisation, as above, or of the substitution of conventional fossil plastics with metals, glass, wood, ceramics and biopolymers, which are increasingly being used outside the packaging sector.⁸

Table 3 Examples of dematerialisation and substitution of plastics in current electrical and electronic equipment

EEE	Examples of dematerialisation	Examples of substitution materials	Example products/ brands
Computer input devices (such as keyboards, mice)	Touchscreen, projection/virtual keyboard, trackpads, gesture-based input devices	Wood, metal, glass, biopolymers	Any tablet PC and many modern laptops, virtual and non-plastic keyboards; well-established gesture products: Microsoft HoloLens, Google Glass, Ultraleap
Televisions, screens	Projectors, tablet PCs, smartphones	–	All well-established markets
Consumer plastic enclosures (both portable and static; mobile phones, laptops, music systems, etc.)		Wood, metal, glass, ceramics, biopolymers	Most well-established markets; fringe examples include Apple's Ceramic and Titanium Watches, Nimble, Symphonized, SUPLA/Kuender & Co, Corbion Purac (Sherman, 2014)
Kitchen equipment (such as kettles and slow, rice and pressure cookers)	Instant boil taps, multifunctional units (such as cookers)	Glass, metal	Much commercial cookware already steel; multi-function appliances commonplace
Larger EEE (air conditioning units)	Passive temperature control	Metal	Commercial HVAC often without plastic casing, for example, Mitsubishi Electric
Vacuum cleaners	Robot	Fibre, metal	Sanitaire, Metrovac
Refrigerators	–	Metal, bioplastic	Steel exterior common; for interior, see, for example, Electrolux (2018)
Handles	–	Rubber (natural)	See Custom Rubber Corp (n.d.) for more on applications

⁸ Biopolymers (such as polylactic acid and cellulose acetate propionate) are produced directly from non-fossil resources. These are different to the bulk plastics cited here, which can also be produced from non-fossil (including biomass) feedstocks.

5 Pathways to 2050

Achieving our 2050 vision would require various actions to be taken across the sector over the next three decades. This section of the report addresses some of these actions and is set out in three stages. The first sub-section outlines some of the most important changes the sector would need to make to achieve our 2050 vision and when these are likely to be technically possible. The second sub-section provides a brief analysis of current trends in the sector and whether these are steering it towards or away from our low-plastic-consumption scenario. The last sub-section builds on these trends to provide a high-level political-economy analysis, outlining what might be done, and by whom, to guide the sector away from BAU towards achieving the low-plastic-consumption scenario. This includes the interests and incentives of key stakeholders

that sustain the BAU and how these would need to change.

5.1 Technical possibilities for change

Table 4 lists key actions required to achieve the low-plastics-demand scenario in 2050 and when each of these actions is likely to be technically possible. This is distinct from when they are likely to be implemented (which involves political, economic and behavioural considerations). We divide the actions into three degrees of technological readiness:

- **possible now** – changes that can be made today with existing technology
- **possible soon** – changes for which the technologies required are already being

Table 4 Indicated timescales for technical advances to achieve the low-plastic-demand scenario

Action	Possible now	Possible soon (by 2035)	Possible later (by 2050)
Define, mandate and enforce standards that ensure EEE is durable, easily repairable and recyclable	✓		
Analyse and remove extraneous plastic (for example, through overdesign)	✓		
Redefine the materials market (by taxation, subsidy or regulation) to promote the use of sustainable non-plastics and recycled plastics over virgin fossil plastics	✓		
Develop material and sustainability impact datasheets that permit direct comparisons between subcomponent options	✓		
Publish aggregate material use and embodied carbon for each appliance alongside current energy labelling	✓		
Amplify current WEEE monitoring systems and redefine WEEE recycling targets to be material-specific	✓		
Enforce the Basel Convention (prohibit the export of WEEE to informal recyclers)	✓		
Redefine the recycling market, for example through EPR schemes, to prioritise reuse over recycling both via in-house take-back schemes and universal end-of-life schemes	✓		
Identify and develop alternatives to current niche plastic uses in the EEE sector (for example, alternatives to PS/PUR as an insulation material in refrigeration appliances and to PVC/PE for cable/wire insulation)			✓

developed and which typically require incremental advances or repurposing of existing technologies

- **possible later** – changes that require fundamental technological advances, which may be at the concept stage of technological development or require a plausible but unrealised technological breakthrough.

These actions are specific to plastics used in the EEE sector and complement those set out in the companion synthesis report on plastics in general (for example, to phase out toxic additives and develop wide-scale chemical recycling). These plastic-focused technical actions also complement the broader societal changes that would lead to the outcomes envisaged in the LED scenario (e.g. clean, compact cities and the sharing economy) and the policy and sectoral trends described in the following sub-section.

5.2 Directions and trends

5.2.1 Markets exist for the reuse, reconditioning and repair of EEE

In Singapore in 2015, 25% of consumers who were upgrading their mobile phones traded in their prior phone to be reconditioned and resold (Deloitte, 2015). This figure does not include the large proportion of phones that were donated to family members or sold privately. A premium smartphone typically had three or four owners before being retired (Deloitte, 2015). Expanding reuse of EEE would be supported by an already well-established reconditioned appliance industry. Strong growth is forecast in the resale of laptops (Future Market Insights, forthcoming), while many manufacturers and retailers already have outlet stores⁹ and many larger appliances (such as washing machines) have historically been repaired rather than replaced.

In addition to the reuse that occurs through the resale of second- (or third- or fourth-) hand EEE, official take-back channels that facilitate factory reconditioning of EEE exist for many sectors. Greenpeace (2017) notes that HP, Dell, Lenovo and Microsoft already offer a wide range

of refurbished products in mature markets and that other brands, such as Xiaomi and Samsung, have a limited offering of refurbished products. Refurbished versions of electrical appliances are also widely available (see Dyson, n.d.; Walmart, n.d.; KitchenAid, n.d.). However, at a national level, reuse via official channels is considered to be insignificant in every country where data exist to monitor it (Ibanescu et al., 2018).

5.2.2 Alternatives to private ownership of physical EEE are well-established and growing

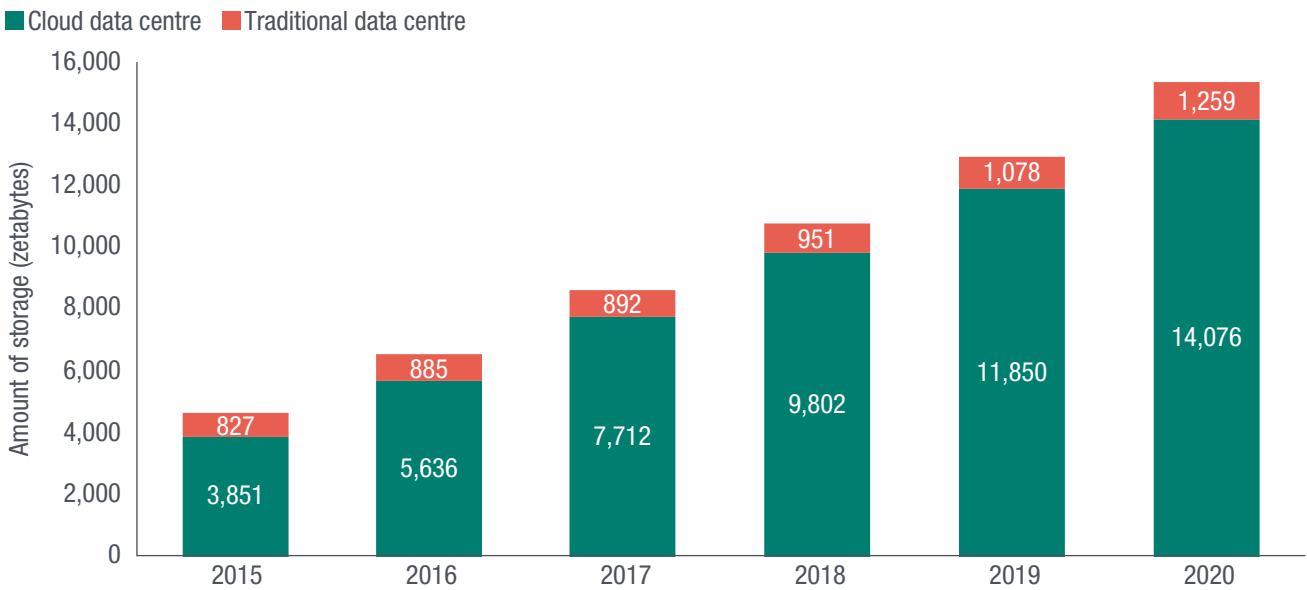
Durable and repairable EEE reinforces the business case for EEE rental and DaaS business models, and vice versa. The consumer electronics rental market in the US alone was valued at \$9 billion in 2019 (IbisWorld, 2019), and many organisations have already adopted DaaS. Moving away from the dominant private ownership model for some EEE could be accelerated by technological changes in other sectors helping to change perception. For example, in the US, around one-third of all new cars and vans are rented rather than owned (Statista, 2019), but this figure is 80% for electric vehicles (Stock, 2018). The projected shift towards electric vehicles could sensitise more consumers to service-provision models, with knock-on effects on EEE ownership.

Entertainment, work and administration increasingly involve connecting to online data storage, which is growing much faster than local data storage on physical EEE infrastructure (Figure 9). Combined with a shift towards device consolidation, as we will discuss, this could remove the need for many EEE devices altogether – from games consoles, TV receivers and DVD players to printers, scanners and office telephone systems.

The sharing economy is well-established in several sectors (PWC, 2015) and could be further adopted if urban densification strategies materialise, as discussed in the automotive- and construction-sector reports. This could impact both the domestic sector (for example, for low-utilisation EEE, such as washing machines and power tools) and the commercial sector, where the shift to cloud-based storage could facilitate a

⁹ See, for example, Dyson (n.d.) and American Freight (n.d.) for kitchen and household appliances.

Figure 9 Projected growth in cloud and traditional data storage



Source: Greenpeace (2017)

transition away from traditional offices towards shared working spaces that yield far lower EEE/employee ratios.

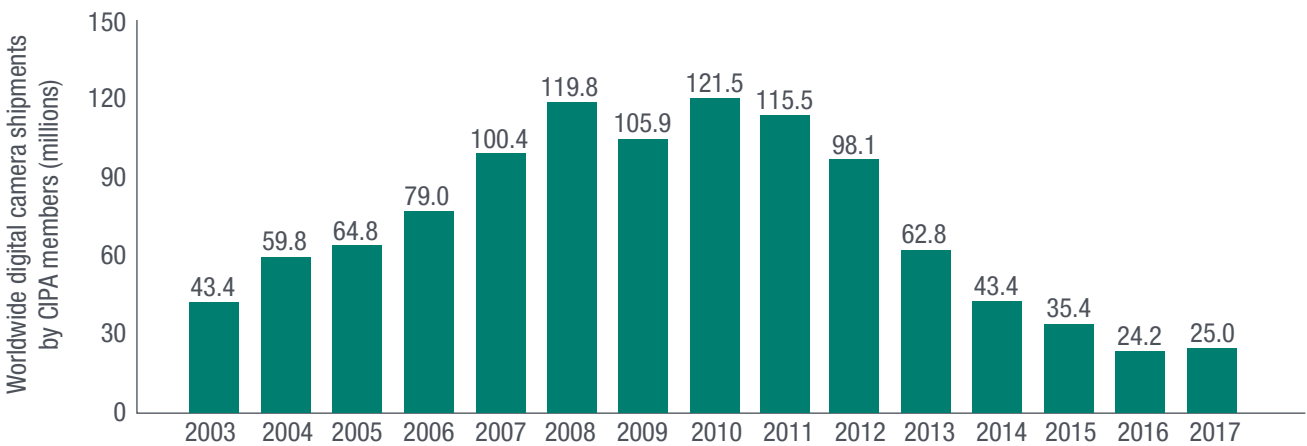
5.2.3 Device consolidation is occurring, but total device numbers continue to increase because of duplication, population growth and increased prosperity

As detailed in chapter 4, the demand for individual EEE appliances could also decline as ‘super-devices’ perform functions previously carried out by many individual appliances, as has happened, for example, with digital cameras due

to the growth of camera-enabled smartphones (Figure 10).

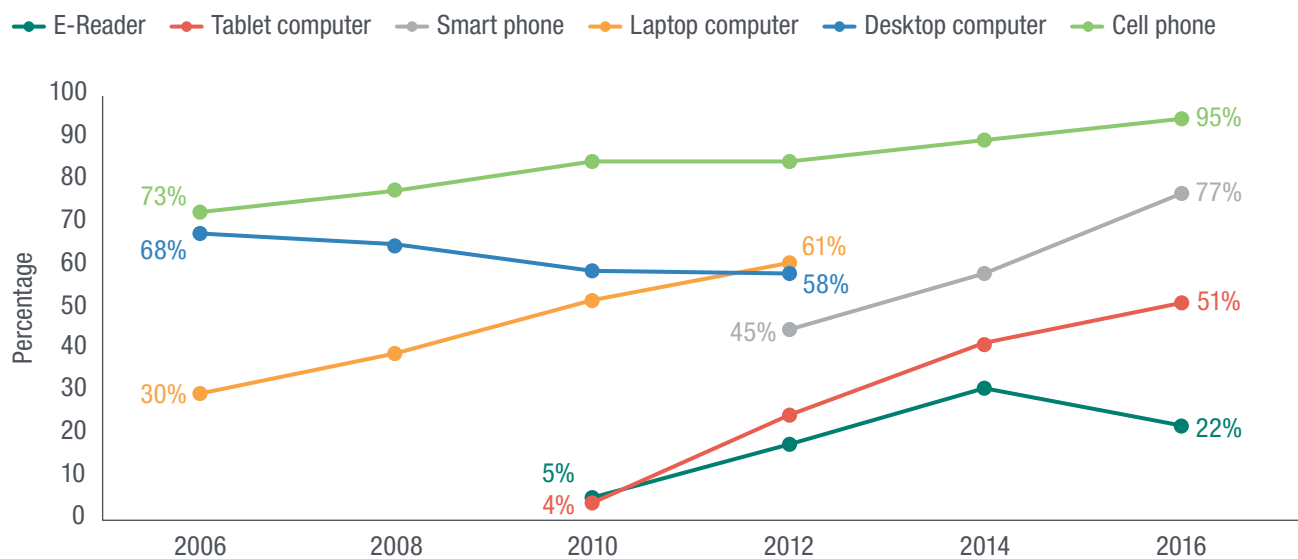
The extent to which this trend will affect different EEE appliances is unclear. For example, Greenpeace (2017) shows how an increase in tablet PC ownership coincided with a decrease in ownership of laptops and desktops (Figure 11). However, total computer ownership was still higher in 2014 than in 2010 and was apparently unaffected by the threefold rise in the sale of smartphones across the period. This ‘stacking’ of devices that provide the same service was also borne out by further analysis of the portion of a

Figure 10 Global shipments of digital cameras, 2003–2017



Source: Bernard (2018)

Figure 11 Proportion of American adults owning various information and communication technology devices



Source: Greenpeace (2017)

population that owns several devices. However, it is not clear whether new ‘super-devices’ are not being immediately substituted for older ones because consumers actively choose to have two separate devices, or whether they are reticent to relinquish the previous appliance before the end of its useful life (and will not replace it thereafter).

5.2.4 Some companies produce durable, repairable EEE, others design products that hamper recyclability and promote obsolescence

Many commentators have noted that, in general, technological advancement and customer preferences are increasing the pace at which products become obsolete (see, for example, Islam and Huda, 2019; Ibanescu et al., 2018). This decreases EEE lifespans, increases the plastics required to fulfil a given service and results in a rise in associated negative impacts (Wang et al., 2018). Some companies already recognise this and promote longer lifetimes for existing EEE (Fairphone, 2019) and market new EEE with an explicit target lifetime of more than double the current average (Gibbs, 2019;

Baldé et al., 2017). Others invoke sustainability as a reason to consider reconditioned EEE.¹⁰

As well as competing with new trends and technological advances, long-lived EEE must be both robust and easily repairable. Key aspects to increase reparability include using standard parts, avoiding adhesives and the provision of appropriate service manuals and spare parts. Greenpeace (2017) reported that for approximately 70% of the EEE gadgets it analysed it was difficult or impossible to replace commonly failing components. There were, however, considerable differences between brands: it praised HP, Dell and Fairphone for their attempts to promote repairable and upgradeable EEE, but found Apple, Microsoft and Samsung to be ‘moving in the wrong direction’, actively discouraging reparability and lobbying against regulations to promote it.

EEE that has been designed to be repairable and recyclable is more common in some sectors (such as household appliances) than others (Bakhiyi et al., 2018), but new materials, like composites (see, for example, plastic electronic, n.d.), could make future EEE incorporating them harder to repair and recycle than current EEE.

10 Giffgaff (n.d.) cites reconditioned handsets as being a ‘More sustainable way to buy a phone’.

5.2.5 Many companies are already removing virgin fossil plastics from their supply chain

For example:

- Apple is ‘transitioning to bio-based and recycled alternatives from petroleum-based plastics’ as part of its broader drive to achieve a closed-loop supply chain (Apple, 2018: 3).
- ABB has created a ‘new recyclable wiring accessories cover frame [that] offers all the benefits of plastic without damaging the environment [...as it...] replaces traditional thermoplastic frames with a new bio-material’ (ABB, 2018).
- Electrolux doubled its use of recycled plastics between 2014 and 2016 and aims to triple that again by 2020 and ‘has developed a refrigerator prototype where all the visible plastic parts are made of bioplastics from renewable sources’ (Electrolux, 2016; 2018).
- ‘Panasonic will adopt a [55%] plant-derived plastic to produce refrigerators, vacuum cleaners and other home appliances within a few years [...and...] will also look into switching to 100% plant-derived material in the future’ (Kawasaki, 2019).

5.2.6 Safety concerns are slowly leading to the phase-out of some plastics and additives

Regulation in the United States and EU has prompted controls on many of the widely used plastic-additives phthalates, with bio-based alternatives made from corn, soy, rice, wheat and linseed gaining in popularity (Pecht, 2018). Many companies have also voluntarily committed to removing certain plastics and additives from their products, although progress here has been limited. Greenpeace (2017) reports that, while numerous companies that produce EEE vowed to phase out PVC and BFRs in 2009–2010, only two (Apple and Google) had achieved this across their portfolios. At the consumer level, a campaign by British consumer group *Which?* resulted in new design standards for refrigerators that outlawed the use of flammable plastic back panels, endorsing metal and aluminium laminate alternatives (Slater, 2019).

5.2.7 Biopolymers with comparable specifications to fossil plastics are becoming available

As noted in chapter 4, many EEE producers already use biopolymers (such as PLA) that can act as drop-in substitutes for bulk fossil plastics. In addition, bioplastic manufacturers continue to develop high-specification plastics that could replace some technical plastics. ABM Composite, for example, has developed a bioplastic that can tolerate stress under temperatures of up to 160°C (ABM Composite, n.d.). Opportunities for the partial substitution of fossil plastics also exist. Lubrizol makes a well-established bio–fossil plastic blend (30–70% bio-based materials) with comparable properties to fossil-fuel-derived plastics, which is already used in consumer electronics products (Lubrizol, n.d.).

5.2.8 WEEE recycling is well-established, with political support around the world

WEEE legislation around the world has evolved, both from the perspective of waste management and the circular economy. It includes mandates and incentives for dealing with plastics in WEEE, as in the EU, China and Japan, for example (Li et al., 2019; Ibanescu et al., 2018; Gu et al., 2017), mandates for design that facilitates better recycling, such as the EU Directive on Eco-Design (EU, 2019; Li et al., 2019), and requirements for minimum recycled plastic content in EEE, such as the 25% requirement in the US (Vazquez and Barbosa, 2016). In China, the launch of an e-waste recycling fund in 2012 established a mechanism through which manufacturers pay levies and the government pays subsidies to e-waste recycling companies, depending on the

Table 5 Sample rates paid to recycling firms under China’s waste electrical and electronic equipment fund

WEEE item	EPR fee (¥)	Recycling subsidy (¥)
Television	13	60–70
PC	10	70
Refrigerator	12	80
Air conditioning unit	7	130
Washing machine	7	35–45

Note: EPR, extended producer responsibility.
Source: Zhao and Yang (2018)

type of WEEE they recycle (Table 5). In the EU, WEEE regulations have been tightening in recent years to progressively increase the proportion of WEEE that is recycled (Figure 12).

The Solving the E-waste Problem (StEP) initiative was founded in 2004 to bring together different approaches from across the EEE and waste sectors. It is housed within UNU and currently has 35 members from government, industry and academia (StEP Initiative, n.d.). A recent report by StEP (Baldé et al., 2017) showed WEEE legislation rapidly entering into force, with taxation and EPR legislation to increase WEEE recycling rates already covering two-thirds of the global population by 2017.

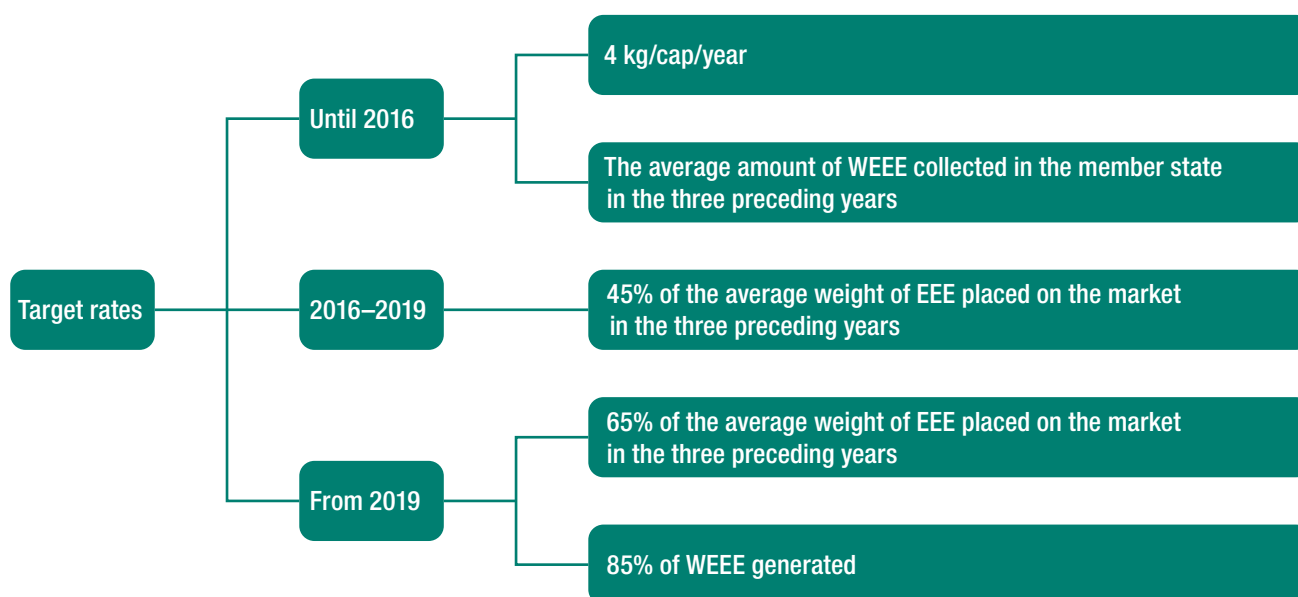
Most of the firms reviewed by Greenpeace (2017) offered some form of take-back scheme. The same report noted that HP took back the equivalent of 11% of its annual sales in 2016 and that Dell sourced approximately one-third of the recycled plastic it uses in new products from its own take-back scheme. In some cases, these take-back schemes are entirely voluntary on the part of the customer, whereas others provide incentives. One small-scale example (targeting 4,000 cellphones in 2019) is Fairphone, which offers a €40 discount for an old Fairphone and €20 for any other trade-in (Fairphone, n.d.a).

5.2.9 Data on plastics use and end-of-life fate are poor, but some initiatives are starting to shed light

The EEE sector is thought to be growing at anything from 1% to 5% per year in advanced economies, and from 10% to 25% per year in developing economies (Forti et al., 2018), but the impact of this on the composition and amount of waste at a disaggregated level is largely unknown. Greenpeace (2017) notes that some companies (Dell and Apple) publish relatively comprehensive material composition data, while other companies (HP, Samsung, LG, Huawei, Microsoft and Lenovo) provide some disaggregated data. Data on in-house reuse and recycling schemes are usually not published (HP is the exception), making it difficult to evaluate the effectiveness and scale of these schemes. The opacity of what happens to plastics that are collected as part of WEEE has persistently allowed such plastics to leak from formal recycling schemes to informal and unsafe recyclers (Puckett et al., 2016; 2018). In addition to a need for tighter enforcement, digitalisation and social networks could help shift recycling to the formal sector (Sun, 2018; Cao et al., 2018).

To better understand the material flows throughout the EEE sector in 2017, the International Telecommunication Union

Figure 12 Increasing targets for waste electrical and electronic equipment recycling rates in the EU



Source: Ibanescu et al. (2018)

(ITU), UNU and the International Solid Waste Association (ISWA) founded the Global E-waste Statistics Partnership (GESP), which is building a statistical library for e-waste and shares best practice for e-waste recycling (GESP, n.d.).

5.3 High-level political economy analysis of the EEE sector

5.3.1 The current situation

The broad use of plastics in EEE is predominantly down to their ability to meet structural specifications at lower production costs than other materials. Few plastics are used for high-end technical purposes in the sector. Most production of electronic devices is dominated by companies in a few countries in Asia (Greenpeace, 2017), which are set to see increased demand, as the sector is projected to grow rapidly. Unlike electronic devices, which are shipped globally, electrical appliances tend to be manufactured domestically or regionally. As with plastic packaging, most EEE plastic waste from wealthier countries is exported.

5.3.2 Pathways to change

China's National Sword policy, banning plastic waste imports, has affected the ability of wealthier countries to export their plastic waste. Discontent also appears to be growing in substitute countries, which are keen not to become waste dumping grounds and are moving to ban waste imports (GAIA, 2019). In both the packaging and electronics sectors, the disruption this has caused to the waste management systems of Western countries could be seen as a window of opportunity for campaigners. As set out in our 2050 vision, reduced plastic usage in the EEE sector depends heavily on improved recycling and reuse rates. The increasing difficulty of exporting e-waste could set this change in motion, demanding government investment in domestic e-waste recycling systems, standards for product labelling and additives, and momentum behind EPR systems.

Part of the pathway to change involves focusing on EEE producers and their supply chains. Increased consumer awareness of plastic usage – and most likely waste – in EEE could be channelled through campaigns at these producers. Achieving the 2050 vision is likely

to require some large EEE producers to see public relations or commercial benefits from commitments to replace plastic use in their products. Private-sector support for reductions in the total number of EEE units in circulation may be sought from large or influential producers of multi-function EEE.

Government policy can build on voluntary actions by private companies and the experience of other sectors. One lever governments could pull is to tighten EPR schemes, which assign producers 'the financial and/or physical responsibility for the management of end-of-life products', calling on producers 'to internalize waste management considerations into their overall product strategies' (Kalimo et al., 2012: 274). Some of the more prominent applications of EPR are already in use in the EEE sector (Kalimo et al., 2012), for example take-back requirements, advance disposal fees and deposit-refund schemes (OECD, 2016). Gaulke (2014) describes some of the political challenges of getting such EPR policies adopted in the United States. Industry opposition and the framing of these schemes as 'job-killing' can be expected. Gaulke (2014) suggests that successful implementation will probably require: (1) environmental NGOs working with selected local-level government actors; (2) the channelling of public environmental concerns around EPR policies and an understanding that recycling issues have not 'been solved'; and (3) finding private-sector allies that stand to benefit from more environmentally friendly product design.

5.3.3 Obstacles

A key challenge to achieving the 2050 vision will be limiting the growth in demand for new EEE between now and 2050. That this growth is driven by increased demand from the Global South may create particular difficulties. Lower average standards of living could mean that the affordability of EEE, and hence price efficiency of material inputs, might be of even greater importance in these markets. The costs associated with internalising externalities related to the production and recycling of plastics in EEE, and the extra upfront costs associated with more durable EEE, could limit the effectiveness of

consumer campaigns related to e-waste recycling or the sustainability impacts of EEE.

The EEE sector consists of many well-known brands with a degree of market power and brand loyalty. Incentives for producers to limit the reparability and upgradability of their products will remain as long as they expect to retain customer loyalty through repeated iterations of products. Challenging these incentives could require quite substantive shifts to the structure of these markets and level of competition, in addition to increased consumer awareness and demand for more repairable products.

Spurring industry action on plastics in EEE may be more difficult than in other sectors. Dauvergne (2018) describes the favourable conditions for a rapid phase-out of plastic microbeads, for example, which would mean no price increases for consumers and only limited additional costs for transnational corporations. Realising this, some corporations voluntarily committed to phase out microbeads before legislation was passed to protect their image.

Dauvergne (2018) suggests that this will be more difficult for plastics in consumer goods, such as electronics, where the political and corporate resistance to change is more significant.

5.3.4 Building a coalition for change

After plastic packaging, the use of plastics in EEE is probably the most consumer-facing sector analysed in this study series. Thus, it is well-placed to build on existing public and policy momentum against waste (particularly of single-use plastics and e-waste). Initially, activism could target producers and marry issues of obvious consumer concern, notably the cost of regularly having to replace rather than repair electronic goods, with the environmental and climate costs that replacement entails.

In the longer term, the persistence of challenges associated with e-waste indicates that a coalition of engaged consumers and leaders from the private sector is unlikely to be enough to achieve the scale of the vision. This is likely to require policy change.

6 Outcomes in 2050

6.1 Materials forecasts

Our projections for the potential reduction in the consumption of virgin plastic products in 2050 compared with BAU are based on several steps. The first is the reduction in activity compared with BAU and the potential for reuse, which together effect a 12% decrease, as set out in chapter 4. Chapter 5 shows how the intensity of plastic use in the remaining 88% could be cut by substitution.

Many, if not most, plastic uses in the EEE sector have readily available substitutes that are not derived from fossil-fuel sources and can be entirely substituted from a technical point of view. Nonetheless, some uses do not yet have drop-in substitutes available. Without any other data, we conservatively assume that the existence of some non-fossil alternatives (such as wood,

metal and glass casings) and ongoing research and development efforts to produce and scale up others (such as biopolymers) would allow half of the residual demand (44% of BAU) to be met by non-plastic sources in 2050. The remainder (44% of BAU) would need to be met by plastic material that was, in order of preference, mechanically recycled, chemically recycled or derived from non-fossil sources (see the companion synthesis report for a discussion of the upstream implications). We conducted no analysis of additives or ‘other’ plastics used in the sector, which account for 28.2% and 18.2% of total demand, respectively (Geyer et al., 2017). Rather, we assume that the reduction in demand for other plastic types and additives is proportional to the average reduction in bulk plastics. Table 6 details the changes in demand for the various plastic types, aggregated in Figure 1.

Table 6 Estimated change in fossil-fuel plastic demand

Plastic type	Mass under BAU	Reduction due to 12% decrease in activity vs BAU	Reduction due to 50% substitution	Change compared with BAU	Residual plastic demand
	Mt	Mt	Mt	Mt	Mt
PE	6.4	-0.8	-2.8	-3.6	2.8
PP	8.2	-1.0	-3.6	-4.6	3.6
PS	5.5	-0.7	-2.4	-3.1	2.4
PUR	3.7	-0.4	-1.6	-2.1	1.6
PVC	3.7	-0.4	-1.6	-2.1	1.6
Others	9.2	-1.1	-4.0	-5.2	4.0
Additives	14.4	-1.7	-6.3	-8.1	6.3
Total	51.0	-6.1	-22.5	-28.6	22.5

6.2 Greenhouse gas emissions and sustainability considerations

Reducing the demand for virgin plastics, per our 2050 vision, could reduce GHG emissions by as much as 50% compared with emissions in 2015 and more than 80% compared with BAU. This would depend on the effectiveness of controls to limit the GHG intensity of substitute materials (for example, to avoid creating emissions through land-use changes) and decarbonisation efforts throughout the value chain (for example, in transportation and end-of-life disposal). Estimating net changes will require comparisons based on the service required (such as GHG emissions per unit of service rather than per kilogram of material). In cases where using alternative (including recycled) materials also creates GHG emissions, the net reduction in GHG emissions from avoiding virgin plastics use would be smaller. Conversely, alternative materials that act as carbon stores, such as products made from timber and agricultural residues, could yield larger net reductions in GHG emissions than the mere avoidance of virgin fossil-plastics consumption.

Although many examples of non-plastic components exist, detailed assessment of the impacts of their substitution is beyond the scope of this study, not least because much of the 2050

data required for such analysis does not exist. Our focus on 2050 also cautions against making comparisons using current lifecycle data, because production systems under the LED scenario – especially energy-production systems, which are a key driver of lifecycle GHG emissions for manufactured products – would be vastly different in 2050 to those today.

In addition to any impacts on GHG emissions, a consideration of the impact of any substitutions would also need to include a full range of sustainability factors, including other environmental pollutants and social impacts.

6.3 Waste

Geyer et al. (2017) report that, in 2015, the waste plastic generated by the EEE sector was equivalent in mass to 72% of demand in the same year. Assuming this same ratio for 2050 would result in 16.2 Mt of waste plastics. We assume that plastics recycling in 2050 is carried out holistically across all sectors and that, geographically, waste is produced in proportion to demand for new (mainly recycled) plastic materials. Without data for which plastics are used for which purposes in which regions today, we are unable to project disaggregated waste-generation profiles for 2050.

7 Conclusions

The EEE sector is the smallest source of demand for virgin plastic materials of those considered in our wider study, but was still responsible for 18 Mt of plastic consumption in 2015. Of the four sectors, the EEE sector is notable because the six bulk plastics on which we focus account for the smallest proportion (54%) of total plastic consumption in the sector (Geyer et al., 2017) and no one segment of the EEE sector dominates. Plastic components and subcomponents are found in a very wide array of electrical appliances – from vacuum cleaners and AC units to washing machines – and electronic devices – such as mobile phones, computers and televisions.

The concomitant development of the plastics and EEE sectors has led them to co-evolve, with many products in the EEE sector only becoming widespread since the advent of plastics. Plastics have often been the first-choice material for EEE components because of their ability to meet product specifications at lower production costs than other materials. This has helped drive their growth and probably expanded the availability of these products to lower-income consumers. Despite their near-ubiquity in the EEE sector, few plastics play an intrinsic role in the operation of EEE, but are often used for functions that are not plastics-specific, such as structural support and protective casings.

Estimated average lifetimes for plastics in the EEE sector vary from 2 to 17 years, depending on the application. The disposal of EEE products has been a focus of environmental campaigners and legislators for decades. A limited amount of plastic is recycled as part of broader WEEE recycling efforts, but this is not the primary target of these actions. Many EEE producers already employ recycled plastic in their products.

Our low-plastics-consumption scenario illustrates how the demand for plastic materials could be reduced by 56% in 2050 compared with BAU while making substantial progress towards

other SDGs. With faster growth in prosperity in the Global South, the 2050 scenario projects an increase in demand for EEE services compared with BAU, but the simultaneous fulfilment of this increase in demand with fewer, more durable, multifunctional EEE products. This would yield a 12% decrease in consumption compared with BAU. Further declines in demand would come from reducing the intensity of EEE sector plastics use by substituting plastic materials with non-plastic alternatives. Most of the bulk plastics considered in our analysis have structural and aesthetic roles in EEE that are already being met by other materials in EEE products available today. This plainly demonstrates that it would be technically possible to significantly reduce the demand for plastic materials by 2050. The reduced demand for plastics in our low-plastic-demand scenario could cut GHG emissions by 80% from BAU and 50% from today. The synthesis report also considers the potential for plastics from recycled and non-fossil feedstocks to meet residual demand.

The visibility of EEE products, the emergence of a wider sustainability agenda led by key actors within the industry, and a growing number of rental and service business models underscore the potential to realise this reduction in EEE plastic consumption. However, the key to achieving the scenario will be designing markets that favour durable, repairable and resalable EEE products, rather than low-cost, single-user products. Voluntary and mandatory standards to promote durability, reparability and recycling, directly comparable data on lifecycle impacts and an increased focus on plastics specifically could help shape markets in a more sustainable way, thereby reducing plastic demand. Various actors within the sector are already promoting action on each of these issues. The challenge will be scaling up these efforts, especially in parts of the world where EEE demand is forecast to grow most rapidly.

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