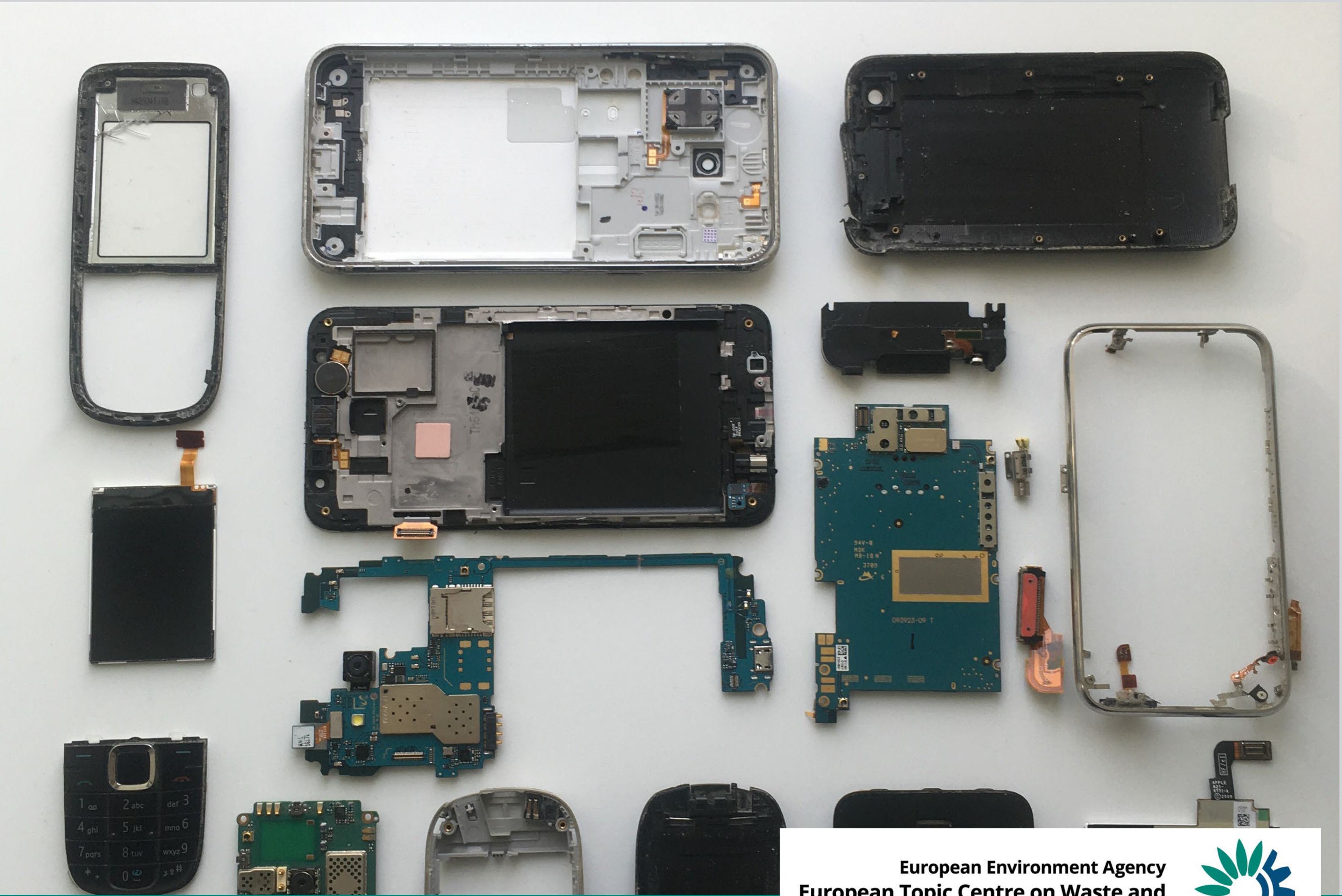
Eionet Report - ETC/WMGE 2020/3

Electronic products and obsolescence in a circular economy

18 June 2020



European Environment Agency
European Topic Centre on Waste and Materials in a Green Economy

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Cover design: European Environment Agency
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Acknowledgement
The authors wish to publish the report in the memory of Sunny-Yang Deng, whose expertise in obsolescence inspired us all and made significant contributions to the report. The authors are grateful to the following experts and organisations for their comments that substantially improved the quality of the report: Josiane Masson (European Commission, DG Environment), Bart Ullstein, Almut Reichel (EEA), Ioannis Bakas (EEA), Daniel Montalvo (EEA), Martin Adams (EEA), Evelien Dils (ETC/WMGE)

More information on the European Union is available on the Internet at http://europa.eu.

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1 Introduction

Over the past century, electrical and electronic equipment, and the industry that produces it, have contributed to enabling welfare, economic growth and job creation in Europe and around the world. Innovation in communication, housekeeping and display technologies, amongst others, has revolutionised the way we live in many ways. At the same time, more information is distributed and shared faster than ever before. When taking account of the stock of electrical and electronic equipment in households, businesses and public spaces, on average a person in Europe owns 44 such devices (Huisman et al., 2017). An example of the enormous amount of electrical and electronic equipment produced annually is the equipment connected to the Internet, which now outnumber humans on the planet (WEF, 2019).

Producing electronic and electrical equipment is, however, a resource intensive industry. A mobile phone, for example, can contain up to 60 different elements from the periodic table. Some of these are on the European Commission's list of critical raw materials, which are of economic and strategic importance but face high supply risks. Extracting, recovering and refining materials for electrical and electronic equipment is resource intensive and use large amounts of water, chemicals and energy: large amounts of energy, for example, are needed to produced ultra-pure input material for microchips.

Besides production and manufacturing, electrical and electronic equipment also require electrical energy in their use phase. The contribution to global warming from different lifecycle phases of electrical and electronic equipment varies considerably between products. For some high-tech and short-lived products, such as mobile phones, the energy required for production can make up up to 85–95 per cent of a device's lifecycle annual footprint (Belkhir and Elmeligi, 2018). When a user discards a device, it becomes waste electrical and electronic equipment which is one of the world's fastest growing waste streams with an annual growth rate of 4 per cent (Baldé et al., 2017). Even though Europe's recycling industry recovers a variety of base metals such as copper, aluminum and iron, as well as precious metals, only slightly less than half of waste electrical and electronic equipment enters official treatment – leaving large amounts untreated (Huisman et al., 2015).

The environmental and climate effects of electrical and electronic equipment have a lot to do with product lifetimes and obsolescence. Electrical and electronic products have very different lifetimes: the lifetime of a mobile phone, for example, is typically shorter than that of a washing machine but their lifetimes differ tremendously depending on several factors including the quality and durability of components and availability of repair services. A device, however, is not necessarily broken when its lifetime ends. This can be the case when the so-called useful lifetime has ended, for example, due to a release of a new more desirable model with improved specifications. The term obsolescence is relevant at this endpoint of useful lifetime. The term "obsolescence" simply defines "the condition of no longer being used or useful"[1]. There are different types of obsolescence, for example mechanical obsolescence when the product no longer functions due to lack of performance of material or components, or psychological obsolescence when a product is replaced because the desire for a new item is strong, although the old one is still functional.

When linking the phenomenon of obsolescence with the fact that manufacturing new consumer electrical and electronic equipment creates environmental and climate impacts such as greenhouse gases and waste, it is evident that increasing product lifetimes is essential for promoting sustainable and green consumption and production. There are several options to tackle this challenge, ranging from circular business models such as products as a service and eco-design to policy measures.

[1] Definition based on https://www.merriam-webster.com/dictionary/obsolete

This report, which provided the analytical underpinning for an EEA Briefing[2] on electrical and electronic equipment and obsolescence in the European circular economy, describes the current system of electrical and electronic equipment from a European[3] perspective – including production and consumption trends, insights on product lifetimes and obsolescence as well as environmental and climate pressures. Four different case studies on smartphones, washing machines, vacuum cleaners and televisions are used to analyse how lifetimes and their impact on the environment appear in practice. Finally, potential business models and policy measures for increasing lifetimes of electrical and electronic equipment are examined.

[2] https://www.eea.europa.eu/themes/waste/resource-efficiency/benefits-of-longer-lasting-electronics

[3] In the report EU will refer to the Member States of European Union where as Europe to the continent.

2 Electrical and electronic equipment production and consumption trends, obsolescence and the environment

2.1 Production and consumption trends of electrical and electronic products

2.1.1 Production trends

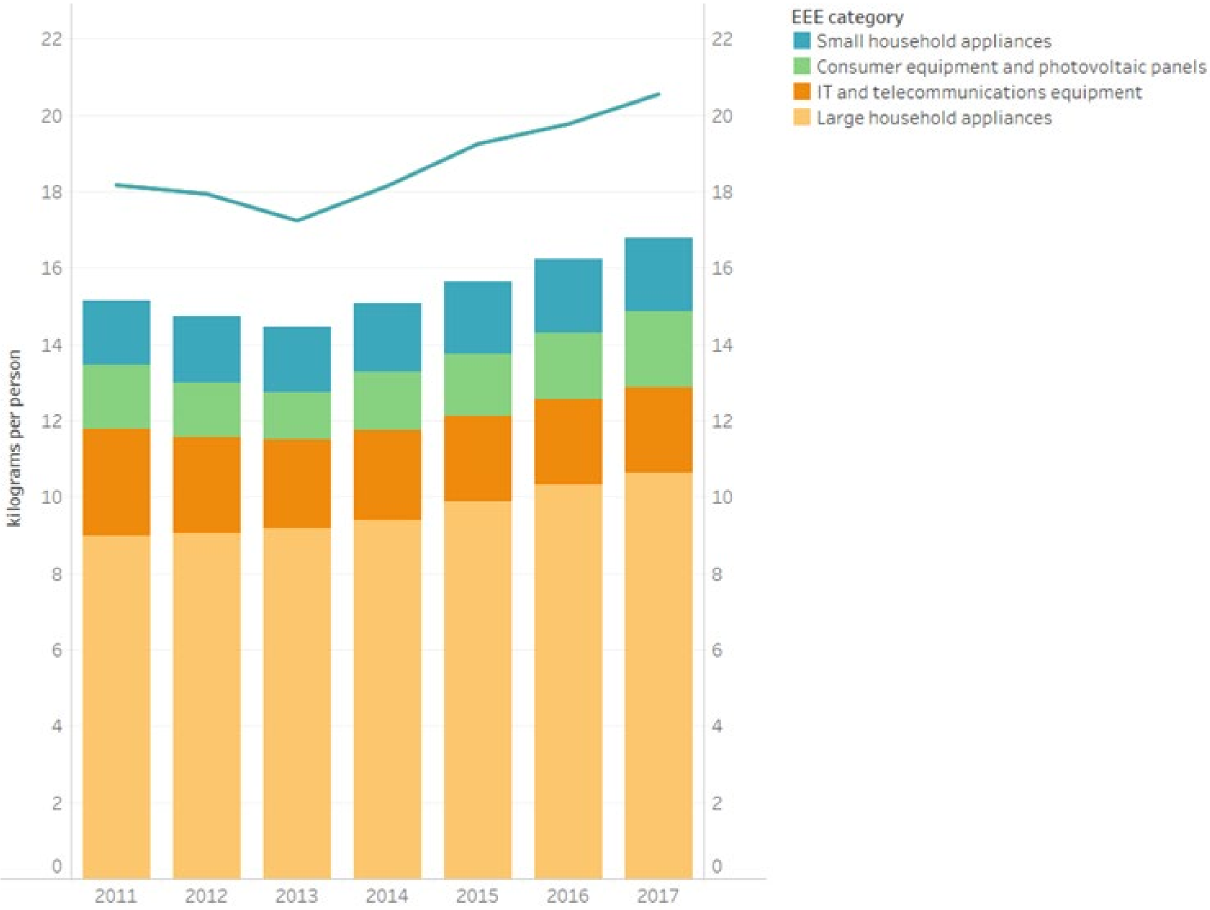
The electrical and electronic industry is one of the largest and most competitive in Europe and the world, producing components and parts for product and application manufacturers in different sectors. In EU, electrical and electronic equipment manufacturing ([4]) employed over 2.5 million people in 2017 in 86,200 enterprises with a turnover of roughly EUR 705,000 million. The sector has been growing steadily since 2012, in some cases in terms of the number of employees and in others in production value and/or volume (Eurostat 2019i).

Electrical and electronic equipment production is highly globalised and is expected to continue to grow as it has over the past decade. A few main drivers of growth of electrical and electronic equipment consumption include the uptake of artificial intelligence; the increased use of mobile, wireless and connected products; and the replacement cycles and decreasing prices of many electrical and electronic devices because of strong competition. The focus for manufacturers will lie in their ability to adapt their products using new data-oriented and clean technologies.

Figure 2.1 shows the amount of selected electrical and electronic equipment placed on the market between 2011 and 2017. It fell 2013, but thereafter rose by 19 per cent overall (Eurostat, 2019h). Large household appliances is the dominant category, accounting for 52 per cent of the total, followed by information technology (IT) and telecommunication equipment, 11 per cent; consumer equipment and photovoltaic panels, 10 per cent; and small household appliances at 9 per cent. Only one category, IT and telecommunications equipment, showed a decrease over time, -4 per cent kilograms per person (kg/person) since 2013, probably due to the diminishing size of smaller products – personal computing equipment, for example, moved from desktop computers, for example, being replaced by laptops and notebooks – as well as the increasing lifetimes of mobile phones. In addition, the purchasing decision for mobile phones is highly connected to consumer sentiment such as short-term expectations about their financial situation, the general economic situation etc. To a certain extent, this sentiment can also be influenced by all kinds of advertisements reaching consumers. Section 3.1 elaborates further on the dynamics of the market for mobile phones.

[4] The manufacturing composes of following NACE_R2 industries: Manufacture of computer, electronic and optical products and Manufacture of electrical equipment

Figure 2.1 Electrical and electronic equipment put on the market (reflected by a line) and for a selection of categories (reflected with bars), EU, 2011–2017, kilograms per person

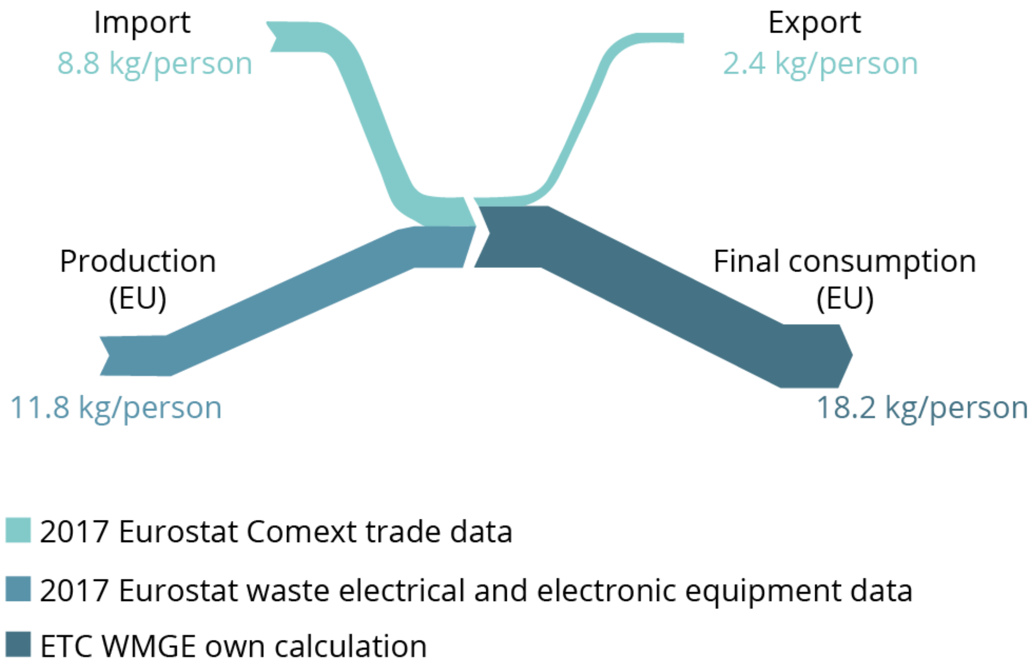


Source: Eurostat, 2019h

Although in the past the EU was a net importer, in 2017 less than half the amount of the electrical and electronic equipment consumed in the EU by weight was imported, 4.5 million tonnes or 8.8 kg/person, and it exported 1.2 million tonnes or 2.4 kg/person (Figure 2.2). Recently, the stock of electrical and electronic equipment within the EU+2 ([5]) was estimated at 128 million tonnes, approximately 244 kg/person, of which just less than 67 per cent was large and small household appliances such as washing machines and coffee machines; 21 per cent cooling equipment and freezers; 7 per cent screens; 5 per cent IT equipment and around 0.4 per cent lighting (Wagner et al., 2019).

[5] EU-27+2 is the 27 EU Member States + Norway, and Switzerland

Figure 2.2 Overview of the import, export, production and consumption flows of electrical and electronic equipment, EU, 2017, kilograms per person

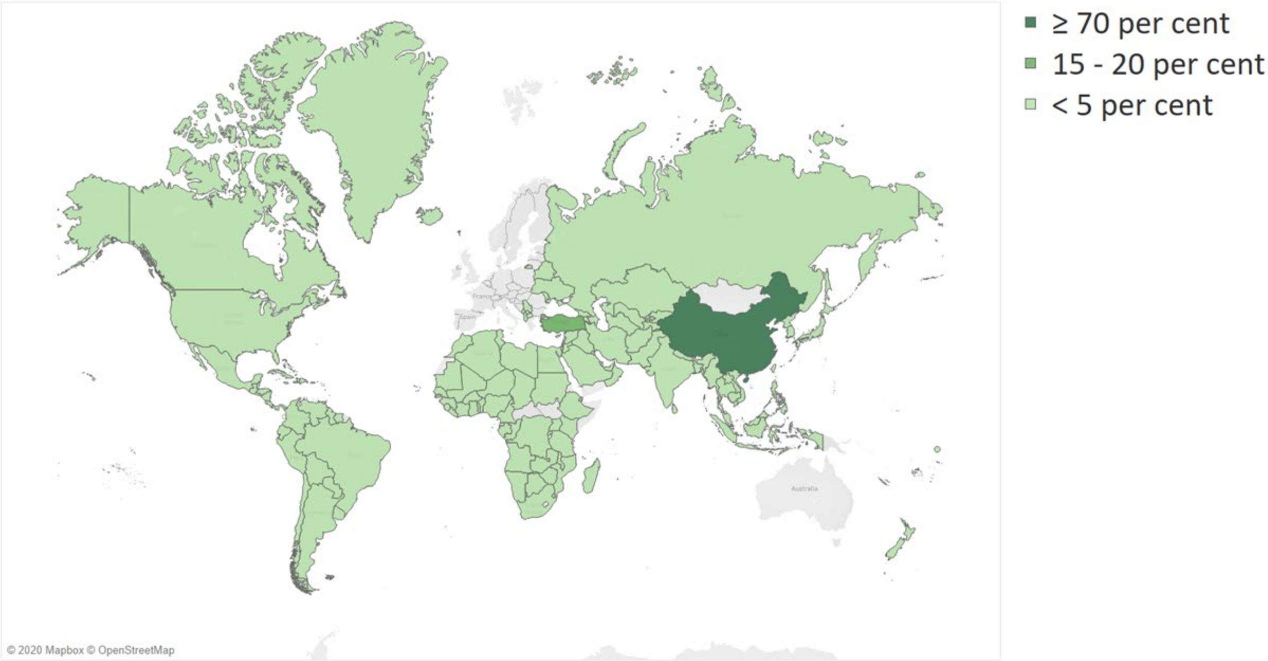


Source: Eurostat, 2019a, 2019g and 2019h

Electrical and electronic equipment, by value, makes up almost 8 per cent of all goods imported by EU Member States in 2018 and the total value of imported goods, has grown steadily, reaching an annual growth rate of 6.5 per cent over the period 2014-2018. The opposite is true of exports: the total value of exported electrical and electronic equipment has fallen by -2,3 per cent since 2014. Expressed in kilograms, the decrease since 2014 was 14.5 per cent.

The manufacturing value chain of electrical and electronic equipment is highly globalised (Figures 2.3 and 2.4) with China and Turkey being important trading partners for the EU. Indeed, 70 per cent of all electrical and electronic equipment imported by the EU originates in China.

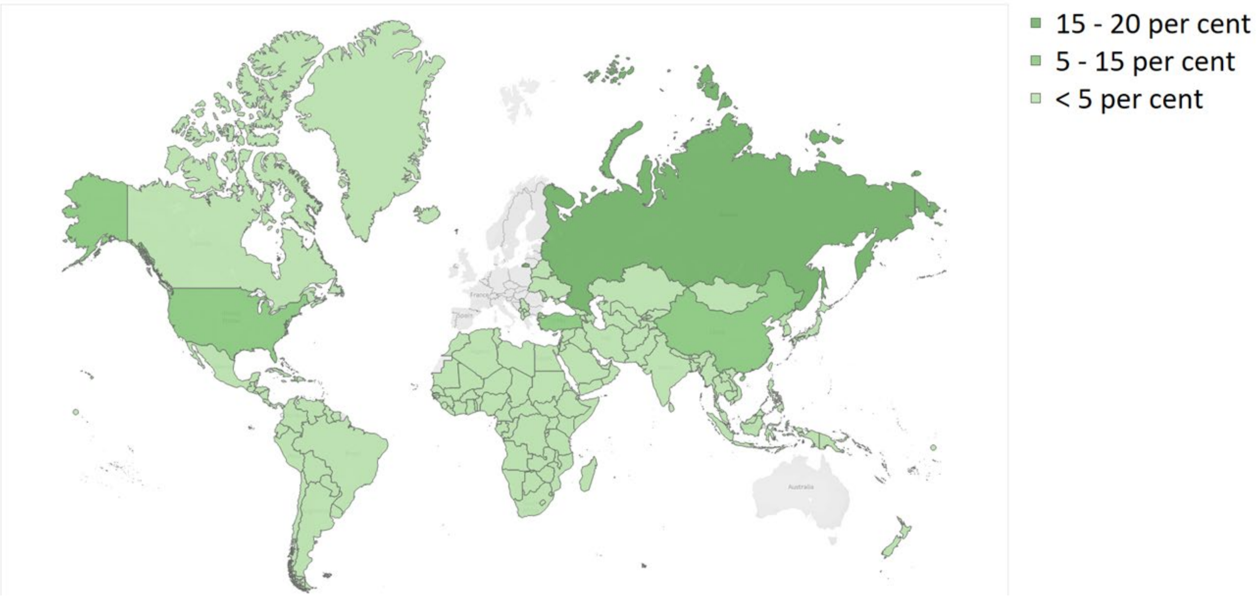
Figure 2.3 EU import shares of electrical and electronic goods, 2018



Source: Eurostat, 2019a

EU Member States export to a wide number of countries around the world. There is no dominant trading partner, but considerable amounts of goods are shipped to the Russian Federation and the United States, respectively 16 and 12 per cent of total EU electrical and electronic equipment exports.

Figure 2.4 EU export shares of electrical and electronic goods, 2018



Source: Eurostat, 2019a

Small and large electrical and electronic household appliances have different trade patterns due, among other things, to their different cost structures.

- The production of smaller appliances largely moved to countries with low labour costs, which is why China has been a significant producer of electrical and electronic equipment for a long time. Now, however, other Asian countries are catching up. Between 2015 and 2018, the Republic of

Korea, for example, increased its trade in small household appliances with the EU by 30 per cent (Applia, Statistical report, 2017/2018).

- The trade in large household appliances is affected by the cost of transport over long distances. Large appliances for use in the EU are largely manufactured in Member States; products that are exported mainly go to the Russian Federation and the United States. The EU also imports significant quantities of large home appliances from Turkey (Applia, Statistical report, 2017/2018).

In 2018, 38 per cent of all home appliances traded globally were produced in China, 31 per cent in Europe, 19 per cent in North America and the remainder in Japan, Russia and the Republic of Korea (Applia, Statistical report, 2017/2018). The sector is, however, constantly subject to challenges such as increased competition from other growing Asian economies. In addition, the Paris Agreement on climate change and the introduction of new technologies, such as artificial intelligence and robotics, are shaping the market worldwide.

2.1.2 Consumption trends

Electrical and electronic equipment can be found in nearly every EU household and consumers buy new appliances on a regular basis.

When looking at the total consumption of electrical and electronic equipment in the EU in 2017, the most recent year for which data is available, household expenditure ([6]) on electrical and electronic equipment was EUR 421 billion – with around 221 million households in the EU (Eurostat, 2019j), this amounts to EUR 1,900 per household.

Of the total consumption of electronic and electrical equipment, 50 per cent was of communication products such as mobile phones, 26 per cent on audio-visual, photographic and information processing equipment such as laptops, 16 per cent on household appliances and, finally, 8 per cent on tools and equipment for houses and gardens (Eurostat, 2019b).

Compared to housing, transport and food, EU household expenditure for electrical and electronic equipment is relatively small – around 5 per cent of total household expenditure in 2017. While the share of electrical and electronic equipment in total expenditure has been stable over time, it was 5.7 per cent in 2009 and 5.4 per cent in 2012, the total amount of all electrical and electronic equipment consumed is growing.

Figure 2.5 provides details of EU consumption expenditure on electrical and electronic equipment ([7]) in 2010–2017. As can be seen, spending for household appliances has increased steadily while spending on telephone equipment (communications) and laptops (audio-visual, photographic and information processing equipment) grew more strongly. This is not surprising as the cost of these products decreased considerably (Figure 2.6) despite rapid technical development.

Figure 2.5 Final consumption expenditure of households for Classification of Individual Consumption According to Purpose (COICOP) categories CP08 Communications, CP091 Audio-visual, photographic and information processing equipment, CP053

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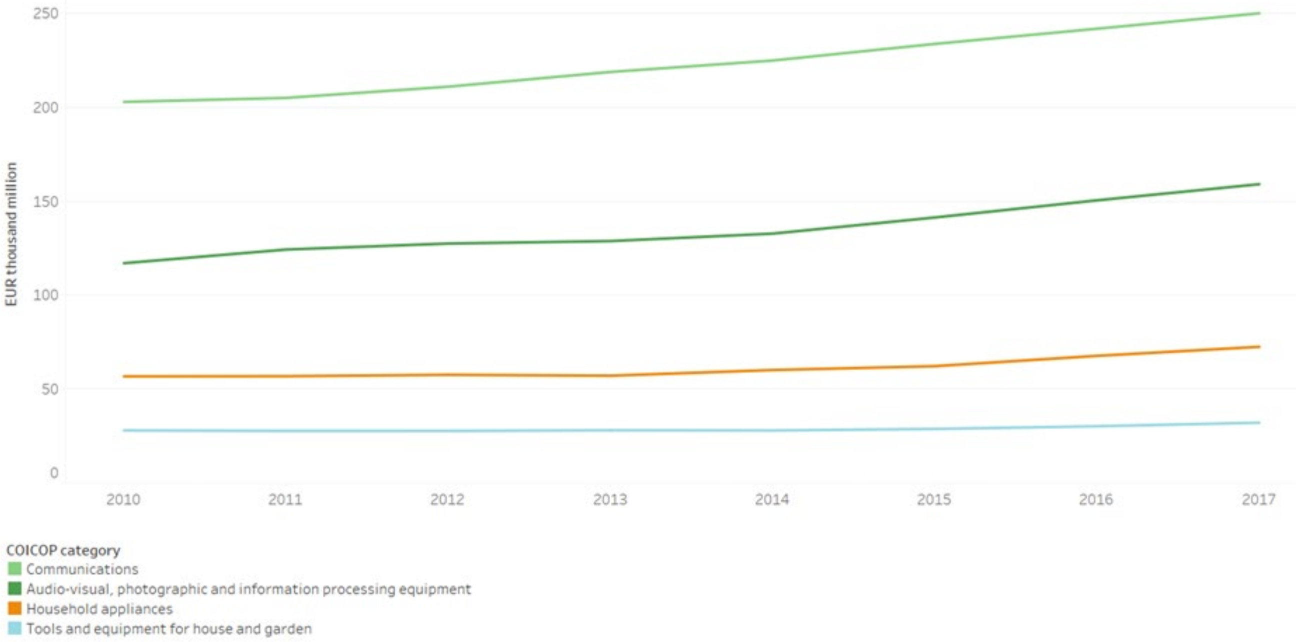
[6] As set by Eurostat, household expenditure refers to any spending done by a person living alone or by a group of people living together in shared accommodation and with common domestic expenses. It includes expenditure incurred on the domestic territory (by residents and non-residents) for the direct satisfaction of individual needs and covers the purchase of goods and services, the consumption of own production (such as garden produce) and the imputed rent of owner-occupied dwellings (https://ec.europa.eu/eurostat/web/products-datasets/-/tec00134)

[7] For measuring the growth rate of the final consumption expenditure of households in terms of volumes, final expenditure at current prices are valued in the prices of a reference year (here 2010) and the thus computed volume changes are imposed on the level of this reference year; this is called a chain-linked series. Accordingly, price movements will not inflate the growth rate (more information can be found on Eurostat).

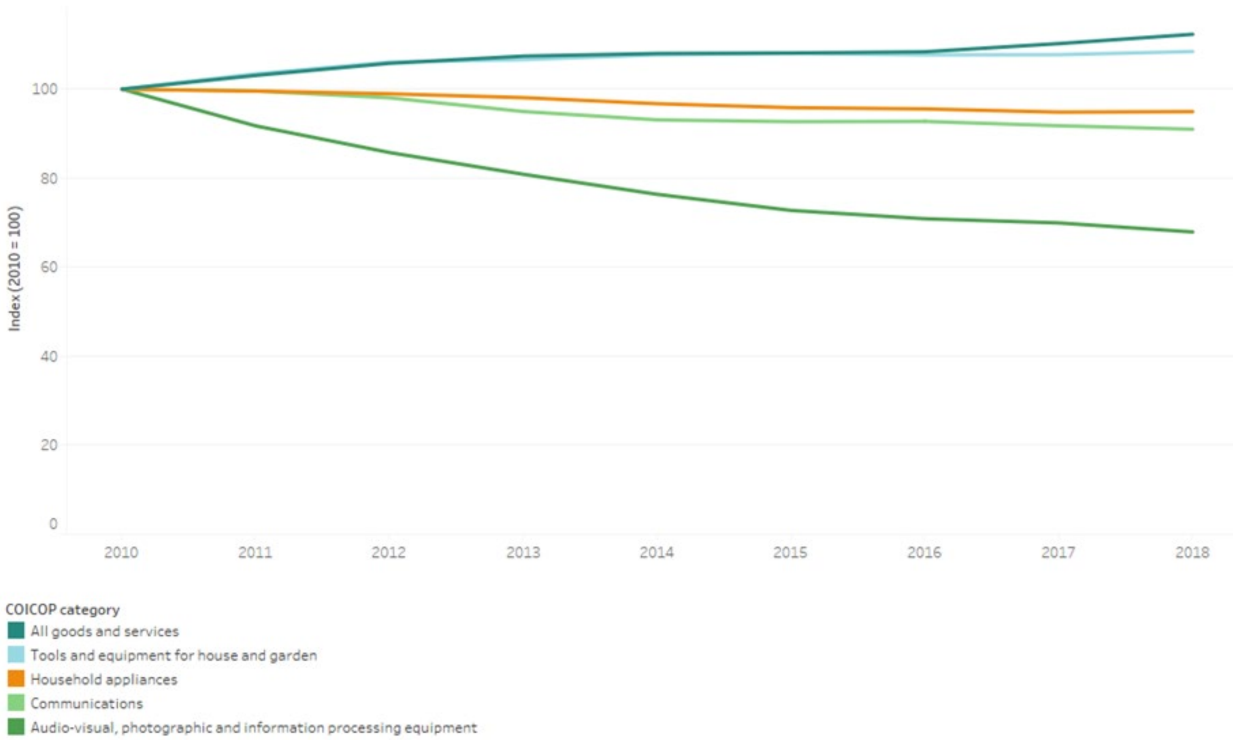
Household appliances and CP055 Tools and equipment for house and garden expressed as chain linked volumes (with 2010 as reference year), EU, 2010–2017, EUR thousand million (10^9)



Source: Eurostat, 2019b

While Figure 2.6 shows a slight increase of prices for goods and services within EU, this trend cannot be observed for more "high tech" products, such as mobile phones and laptops, neither for household appliances.

Figure 2.6 Consumer price index for all goods and services and Classification of Individual Consumption According to Purpose (COICOP) categories CP08 Communications, CP091 Audio-visual, photographic and information processing equipment, CP053 Household appliances and CP055 Tools and equipment for house and garden, EU, 2010–2018, index (2010 = 100)



Source: Eurostat, 2019c

According to Statista and based on information from International Monetary Fund (IMF), United Nations (UN), the World Bank, Eurostat and national statistical offices, consumer spending by private households in Europe, in current prices, is expected to grow annually by 1.9 per cent to 2023. Similarly, demand for telecommunications and household equipment is expected to grow annually by 1.5 and 1.8 per cent respectively to 2023. As Europe's population is only expected to grow very slightly or even decrease (UN, 2019), population growth as such is not a driver.

Other drivers of per person consumer spending are income, household debt levels and consumer expectations. The greater household disposable income, or the more confident people are about their disposable income in the near future, the more electrical and electronic equipment will be bought. Thus, economic growth and prosperity can partly explain the sector's growth trend.

The number and size of households also drive demand for appliances. In 2018, the average size of households in EU was 2.3 people ([8]) (Eurostat, 2019f). This number has, however, decreased over time: in 2010, the average household consisted of 2.4 people. In parallel, the proportion of people living alone is increasing, which, in turn, is linked to the reduction in the longevity of relationships and higher divorce rates. The trend towards smaller household sizes in general leads to the purchase of more appliances, and probably lower usage intensity.

Another reason for this market uptake is the generally perceived shortening lifetimes of electrical and electronic products. Over time, products design has become more complex and devices are becoming increasingly difficult to repair (Section 2.2.2). Given the Circular Economy Action Plan and the intention of the EC to adopt a circular economy, there is an increasing need for more durable products which are easy to repair, reuse or recycle. The Ecodesign Directive already covers environmental impacts along products' lifecycles but the focus so far has been on improving energy efficiency. The new Ecodesign Regulation (EU Regulation 2019/1784) is also contributing to the transition towards a circular economy by including requirements for repairability and recyclability of electrical and electronic equipment.

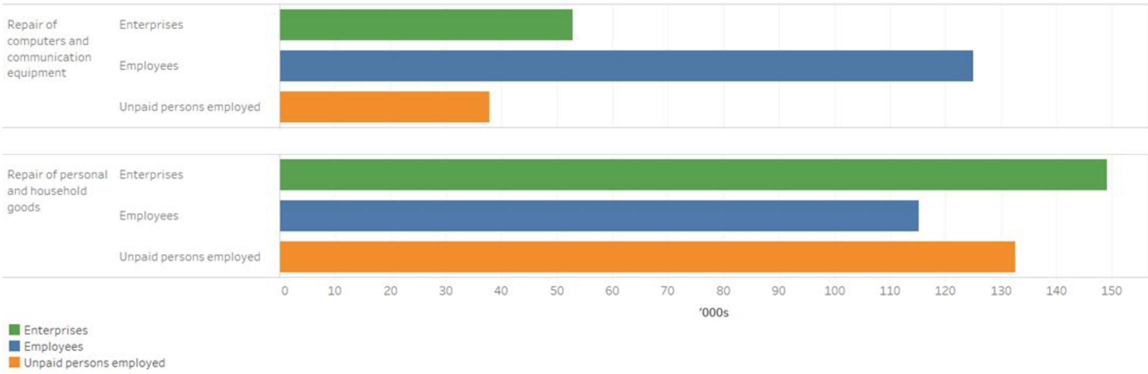
2.1.2.1 Repair

In general, the repair sector can be divided into two subsectors, differentiated by the type of end user. On one hand, enterprises providing services for the repair of computers and communication equipment as their principal activity may provide services directly to end users such as households and business clients, or they may provide specialised services to intermediaries such as manufacturers or distributors. Enterprises providing repair and maintenance services for personal and household goods on the other hand, are generally focused on personal clients (Eurostat, 2019e).

Although to a certain extent the sector depends on the overall economic cycle, as households and businesses might postpone purchases of new (semi-) durable goods and opt for repair instead, the sector turnover rose steadily over the period 2012–2017 (Eurostat, 2019e). There are, however, differences between subsectors: the turnover of repair activities of personal and household goods, for example, increased on average by 3 per cent each year, while the turnover of repair activities of computers and communication equipment grew annually by more than 8 per cent (Eurostat, 2019e). As producers have recently adopted new ecodesign measures for enhancing repairability recently, the repair sector is expected to grow stronger over time.

[8] A household is defined as "a person living alone or a group of people who live together in the same private dwelling and share expenditures, including the joint provision of the essentials of living". Additionally, in higher performing economies, some households may own more than one residence, which could, in turn, further increase the demand for electrical and electronic equipment.

Figure 2.7 EU enterprises, employees and unpaid volunteers employed in the repair of computers and communication equipment, and the repair of personal and household goods, 2017, '000s



Source: Eurostat, 2019e

Figure 2.7 shows the number of enterprises, employees and unpaid volunteers employed in each subsector. In contrast to the repair of computers and communication equipment, repair of personal and household goods is typically offered by smaller companies and this subsector also relies more strongly on voluntary and/or charitable initiatives.

2.2 Product lifetimes and obsolescence

Our way of life has undergone an extensive transformation over the past decades: there has been a clear shift towards an information society, in which the hardware and software of a product stimulate the creation of a personal bond between the user and equipment. As the renewal cycles of knowledge and information technology are faster than those in traditional product development, society is confronted with accelerating product consumption. In addition, consumer electrical and electronic devices have proliferated thanks to technological advancement and falling costs, combined with increasing disposable incomes. Purchasing a new washing machine, for example, cost 59 working hours work in 2004 but dropped to just 39 hours in 2014 (CECED, 2017). This has led to electrical and electronic equipment becoming outdated more rapidly and, as such, less desirable to repair.

Its increased importance in everyday life leading to increased consumption of electrical and electronic equipment, together with the environmental impacts of its manufacture, shows the importance of paying attention to product usage and lifetimes. According to a European Environmental Bureau (EEB) study (2019), extending the lifetime of all washing machines, smartphones, laptops and vacuum cleaners in the EU by one year would lead to annual savings of around 4 million tonnes of carbon dioxide by 2030, which is equivalent to taking over 2 million cars off the roads for a year. As for the end of life phase, recycling obsolete products alone will not be enough to retain the value lost in such a cycle. A recent study for the Swedish Recyclers' Association shows that when the material is recycled three quarters of its value is lost after one use cycle (Material Economics, 2018).

The following two sections describe what is behind the lifetime of a device and how this relates to product obsolescence.

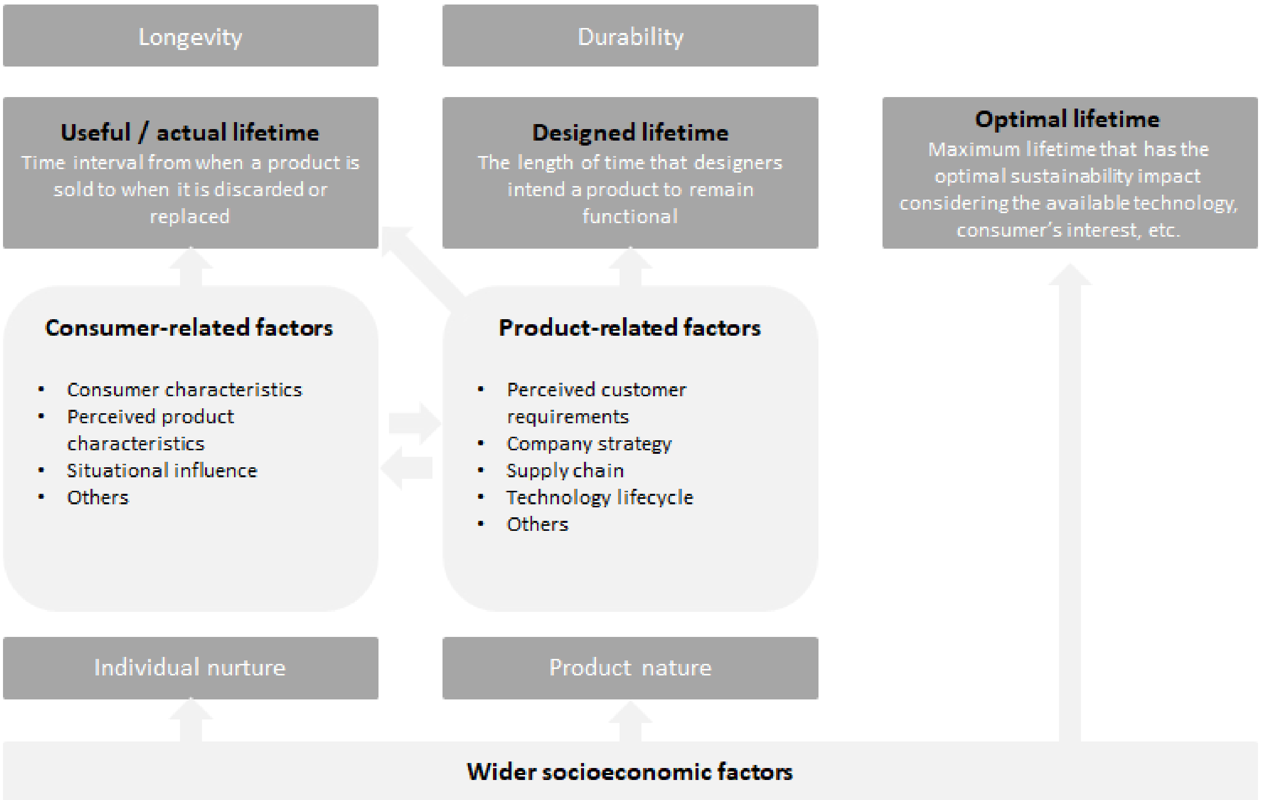
2.2.1 Product lifetimes

Product lifetimes are connected with the concept of obsolescence. A product becomes obsolete when it reaches the end of its lifetime. The term obsolescence simply defines the condition of no longer being used or useful.

To discuss lifetimes and obsolescence, this analysis has used working definitions of lifetimes based on a literature review (Stamminger et al., 2018; Ardente and Mathieux, 2016; Cooper, 2016; Ardente and Mathieux, 2014; Bobba et al., 2012). It should be noted that while the normal unit for measuring lifetime is duration, expressed, for example, in years, for such items as washing machines or vacuum cleaners, operational cycles may be used instead to take account of the intensity of use. This is because the number of operational cycles is a more relevant factor leading to product wear and tear compared with duration (Cooper, 2016). A washing machine, for instance, that is designed for 2,000 cycles is supposed to last for 10 years if it is run for 200 wash cycles per year, but more intense use with a higher number of wash cycles per year will shorten its lifetime in years. A cycle can also refer to products with a battery. Fully charging the battery and draining it, accounts for one cycle. In general, a typical smartphone battery retains up to 80 percent of its capacity after 500 cycles.

Three types of lifetime are defined in this analysis, as listed below and in Figure 2.8, optimal lifetimes, designed lifetimes and useful or actual lifetimes.

Figure 2.8 The lifetime framework approach utilised



Source: Adapted from CSCP

A **useful** or **actual lifetime** refers to the time from the moment a product is sold to when it is discarded or replaced (Murakami et al., 2010, Oguchi et al., 2010). It is determined by the intrinsic properties of the product – product nature – but strongly influenced by the consumer's behaviour, such as how it is used, maintained, repaired and reused – individual nurture. Moreover, social and cultural trends, such as societal norms and values, also exert influence (Cooper 2016). This broader approach, combining social and cultural trends with a product's material properties, is covered by the term product longevity, which describes a product's actual lifespan.

A designed lifetime refers to the maximum lifetime that a manufacturer intends its product to remain functional, which is mainly determined by the product design and after-sale service. It is the result of decisions made at the point of product design, such as the materials used, design quality including considerations of repairability and upgradability, and the process quality. These decisions are influenced by business-related factors, such as the chosen business models, such as rental or sale (Cooper 2016), and the supply chain, for example if some component has obsolescence risks. It is also influenced by consumer-related and the socio-economic factors, such as perceived consumers' expectations, the market structure and conditions, and technology lifecycles (Boulos et al., 2015). The designed lifetime is linked to product durability, which is a product's nature by design, or "the ability of a product to remain functional when faced with the challenges of normal operation over its lifetime" (Cooper, 1994).

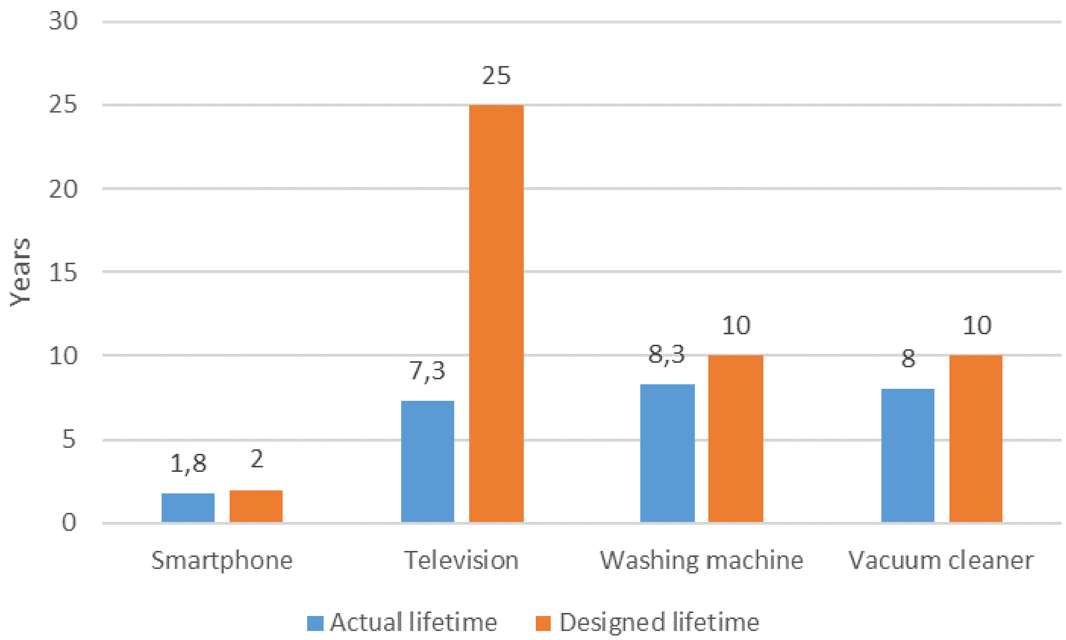
The optimal lifetime refers to the lifetime when a product's lifecycle has achieved the optimal environmental, social and economic impact, taking into consideration the influencing factors on the product, consumer and socio-economic levels. In practice, an optimal lifetime can be challenging to identify due to the multitude of impacts and influencing factors to be considered, which are, in many cases, not that comparable.

From an environmental point of view, a product's lifetime should generally be extended for as long as possible since in theory, roughly speaking, doubling a lifespan will halve the product's environmental impact (Cooper 2016). Energy- and/or resource-consuming products that have the highest impact during the use phase are one of the exceptions and have a tipping point. When the new model is significantly more eco-efficient than the old one, the energy and resources saved by using the new model may offset the environmental benefit gained from using the old one for longer. Research has shown, for example, that refrigerators bought in the UK in 2001 should be replaced after 10 years, but, due to recent eco-efficiency improvements, refrigerators bought in 2011 do not need to be replaced for 20 years (Bakker et al., 2014).

When accounting for other factors in addition to environmental impacts, such as consumers' behaviour and willingness to pay, technological innovation and other socioeconomic factors, the optimal lifetime is complex to define. A lifetime optimisation strategy should create a win-win outcome for consumers, manufacturers and society as a whole with clear targets, such as optimal sustainability impacts; consumer satisfaction, both emotionally, and in terms of a product's function; emerging technological evolution; and societal progress (Cooper, 2016).

In reality, a product's actual lifetime rarely reaches the upper threshold of its designed lifetime, (Figure 2.9) as emotional and socio-economic factors jointly influence the product's lifetime (Cooper, 2016; Schifferstein and Hekkert, 2008). Wieser et al. (2015) found that the actual lifetime is positively related to a consumer's age, household income and educational level. Also, according to this study, low-income groups are most affected by short product lifetimes and are often afraid of taking the risks associated with buying high-priced products as there is a concern among some of the consumers that planned obsolescence is a widespread phenomenon. Frequent moving also leads to considerably shorter actual lifetimes. While the above is more applicable to large household appliances, small domestic appliances are also affected (Wieser et al., 2015).

Figure 2.9 Actual lifetimes compared to designed lifetimes of selected electronic products

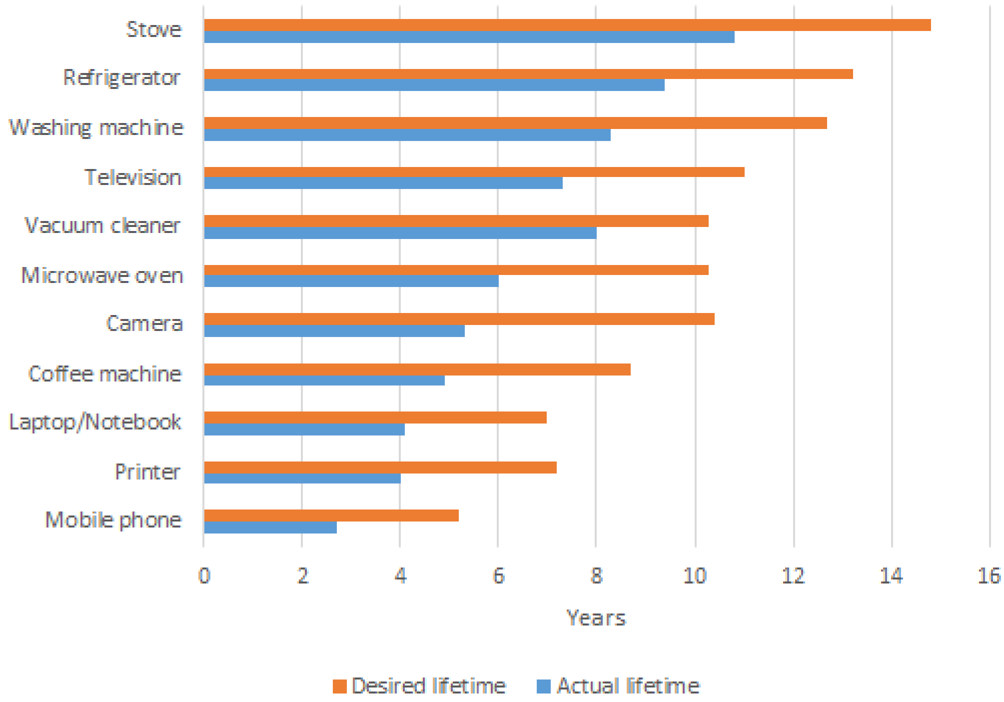


Sources: AEA, 2009; Cordella et al. 2019; EC, 2019e; Kalyani et al. 2017; King County, 2008 Prakash et al., 2016; Wieser et al., 2015

Product-related factors, such as product design, manufacturers' innovation and market strategies, are also determinants (Bocken et al., 2016; Schifferstein et al., 2004). Products are sometimes hard to upgrade and impractical to repair, again limiting their lifetimes. Most smartphones, for example, have built-in batteries that are expensive to replace or repair. In general, these batteries last about two years, making this, next to some other factors, a determining factor for the lifetime.

Next to products being impractical or impossible to repair, of those consumers who decided not to repair their devices 25–50 per cent expected the repairs would be too expensive, 20–30 per cent felt the product was out of fashion and 17–25 per cent expressed a preference to obtain a new product. Some consumers lack information regarding product durability and repairability (5–10 per cent) or feel replacement is more convenient than repairing (8–14 per cent) (EC, 2018a). Consumers with low expectations regarding product lifetimes are more likely to prefer replacements than repair. As consumers generally assume products, especially electronics, will only last for short periods, there is a negative impact on use time (Wieser et al., 2015). At the same time, the **desired lifetime**, or the time that consumers want products to last, is considerably longer than the time they are used (Figure 2.10). Depending on the product, the desired lifetime is 1.73 to 3.62 times higher than the use time (Wieser et al., 2015).

Figure 2.10 Actual lifetime and desired lifetime of selected electrical and electronic products



Source: AEA, 2009; EC, 2019e; Wieser et al., 2015

Studies also contradict the widespread belief in a throwaway mentality among consumers (EC, 2018a; Wieser et al., 2015). In fact, in a study by the European Economic and Social Committee (EESC) it was noted that sales of products with a lifespan labelling increased 13.8 per cent. (EESC, 2016). This indicates consumers' willingness to invest in products which have information on their lifespans.

2.2.2 Product obsolescence

A product becomes obsolete when it is no longer wanted and/or the useful lifetime ends. Multiple studies have discussed different types of obsolescence. In general, product obsolescence can be driven by new design, technical developments or fashion. Van Nes and Cramer (2006), for example, identified a typology for replacement motives, which includes wear and tear, improved utility, improved expression and new desires. The EESC (2013) drew attention to planned, premature, indirect, incompatibility, and style obsolescence. Research has not reached a definitive consensus on the different definitions and typologies of obsolescence, the causes of which are complex and related.

Research has highlighted that obsolescence can be caused by objective reasons, such as a mechanical failure, or subjective reasons, including aesthetic preferences (Bakker and Schuit, 2017; Cooper, 2016; EESC, 2013;). Cooper (2016) has further categorised obsolescence to differentiate the failure of a product to function due to objective reasons, absolute obsolescence, from the disuse of a functional product due to additional subjective reasons, relative obsolescence.

The following descriptions apply Cooper’s absolute and relative obsolescence as the umbrella, and further elaborates specific obsolescence types based on the available research (Bakker and Schuit, 2017; Prakash et al., 2016; EESC, 2013; Cooper, 2004; OECD, 1982).

Absolute obsolescence refers to the failure of a product to function and is mainly influenced by the product nature determined by design. In this case, the actual lifetime equals the designed lifetime. It may be further categorized as follows.

- Mechanical obsolescence: when the product no longer functions due to lack of performance of material or components.
- Incompatibility obsolescence: when the product no longer works properly due to lack of interoperability of software and/or hardware.

Relative obsolescence refers to the disuse of a functional product. In this case, the actual lifetime is less than the designed lifetime. This is a joint result of the product's nature and consumer's decision. This decision can be highly influenced by marketing, sometimes also referred to as marketing-induced obsolescence. It includes further different types of obsolescence, including the following.

- Psychological obsolescence, or style, cosmetic or aesthetic obsolescence: when a product is replaced because the desire for a new item is strong although the old one is still functional.
- Economic obsolescence: when the old product is replaced as the cost of repair or upgrading is high compared to replacement.
- Technological obsolescence: when the old item is replaced as a new product offering better quality, functionality or effectiveness is available.

There is no clear or agreed boarder line between the different types of obsolescence in practice. For example, whether a product without an updated operating system is still functional depends on the owners' subjective judgement. Regardless of a great deal of research on obsolescence, the causal factors remain inconclusive. The types of obsolescence are linked and jointly influence product lifetime – pinpointing any one specific cause is difficult (Prakash et al., 2016).

Differentiating relative obsolescence from the absolute obsolescence, however, can assist discussion on appropriate lifetime optimisation approaches. For products that are often disposed of while they are still functional, for example, improving their physical durability is unlikely to be effective in prolonging their useful lifetimes. Instead, research suggests the implementation of measures to improve emotional attachment (Bakker et al., 2014).

Obsolescence often has negative connotations, especially if it happens earlier than it should. **Premature obsolescence** implies a comparison between the actual and designed lifetimes, and is thus an evaluation (Brönneke 2014). It can occur when a product's useful lifetime does not live up to:

i) what is possible – the designed lifetime; or
ii) what is desirable – the product lifetime as reasonably expected by consumers, or the optimal lifetime from a sustainability perspective, taking state-of-the-art technology into account.

Both relative and absolute obsolescence can lead to premature obsolescence. If the premature obsolescence is intentional, when a product is designed to have a shorter life, consumers are stimulated to repeat purchases, it is referred to as **planned or programmed obsolescence**. Although there have been numerous documented cases, for example products, such as sealed drums in washing machines or mobile phones with non-removable batteries or inkjet cartridges with a chip that prevents them being reused (Aladeojebi, 2013) that are designed to make repair not viable, it remains extremely difficult to prove that the obsolescence is planned (EPRS, 2016).

Premature obsolescence, however, poses problems from environmental and social perspectives, as it may lead to an excessive use of natural resources, an increase in credit purchases, consumer indebtedness and dissatisfaction with the quality and lifespan of products (EPRS, 2016). This dissatisfaction is especially expressed by consumers of electronical and electronic products (Wieser et al., 2015). Nonetheless, it can be argued that obsolescence leads to economic growth, due to the generation of sales, increased competition and investment in research and development, offering better performing products to consumers and increased availability of lesser products to lower income groups.

The main reasons for obsolescence vary depending on the product. For mobile phones, relative obsolescence – the desire for a better mobile product, 22.8 per cent; changes in consumer preferences, 22 per cent; or upgrades,14.2 per cent – is the main driver for consumers to replace their devices. Absolute obsolescence, or the replacement of a mobile phone due to mechanical defects, 31.4 per cent, is less dominant (Wieser et al., 2016).

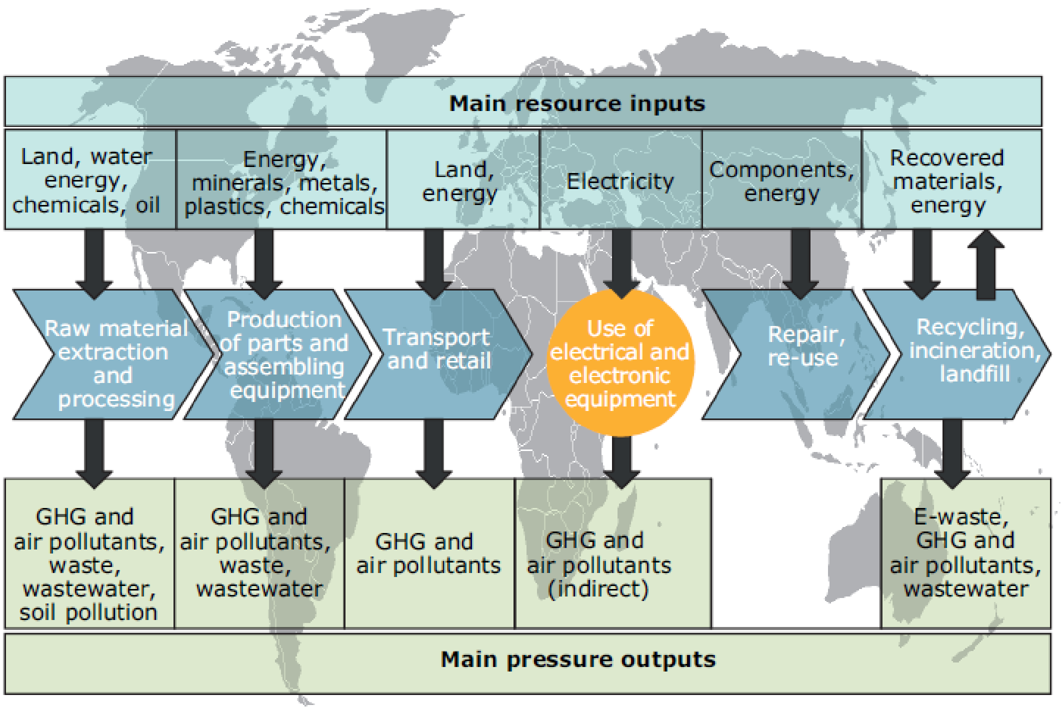
Similarly, the main reason for replacing old televisions is attributed to relative obsolescence. A German study found that more than 60 per cent of fully functional flat screen televisions were replaced in 2012 because their owners wanted a better device (Prakash et al., 2016). For washing machines, absolute obsolescence is the main reason for replacement – 84 per cent of consumers replacing them due to product failure or dysfunction (HOP, 2019).

Product lifetimes and obsolescence are important from an environmental point of view since electrical and electronic equipment is resource intensive, utilising particular materials and chemicals, and requires significant amounts of energy in manufacturing, generating various environmental impacts that will be discussed in more detail in Chapter 2.3.

2.3 Environmental impacts

The electrical and electronic sector is one of the largest and most competitive in Europe and the world, producing components and parts for product and application manufacturers in other sectors. In EU in 2017, electrical and electronic equipment manufacturing employed more than 2.5 million people in 86,200 enterprises with a turnover of roughly EUR 705,000 million (Eurostat 2019i). In order to produce high tech. parts and equipment, a broad range of materials as well as energy is required. Often especially technical materials required in electrical and electronics are mainly imported into EU –some are critical raw materials and rare-earth elements. In addition, ultra clean components and intermediate products require energy, water and chemicals, all of which have environmental impacts. In this section, the environmental impacts are looked at more closely.

Figure 2.11 An overview of the main resource inputs and pressure outputs of electrical and electronic equipment value chain



Source: EEA, 2014

2.3.1 Materials use for electronics

Complex electrical and electronic equipment can contain up to 60 elements from the periodic table (Baldé et al., 2017). Copper is particularly important for the electrical and electronics industry; in EU the sector was the largest end consumer of copper, using slightly more than 1.1 million tonnes annually representing 22 % of the average total copper consumption between 2010 and 2014 (EC, 2017a).

Globally, annual copper ore production averaged 17.1 million tonnes between 2010 and 2014 (EC, 2017a). To produce this, roughly 203 million tonnes of material was extracted from the ground (OECD, 2019a). Copper is used in the production of energy-efficient power circuits due to its good conductivity. In addition, its machineability and formability together with good corrosion resistance makes it an ideal material for wiring.

Other significant materials are gold of which the sector uses 11 per cent of the EU's total consumption of 76 tonnes and silver of which it uses 8 per cent of 12 000 tonnes (EC, 2017a). Both these metals are used in connectors, switches, relays, solder joints, connecting wires and connection strips of high-specification components.

The sector also uses a considerable share of critical raw materials including rare-earth elements which often provide unique properties for components or applications. Without these materials, current levels of miniaturisation and mobility, which are critical, for example, for mobile phones, would not be possible. Gallium and silicon metal are used in the semiconductor industry for integrated circuits, providing, for example, high performance processors for mobile phones, tablets and laptops (EC, 2017b). On average, roughly 70 per cent of the EU's 250–300 tonnes total annual consumption of gallium was used for integrated circuits between 2010 and 2014 (EC, 2017b).

Interestingly, helium, a critical raw material, is an important element used in the sector in the manufacture of semiconductors. Other critical raw materials it uses are beryllium, cobalt, hafnium, indium, platinum-group metals and some rare-earth elements, for example, europium, terbium and yttrium in luminophores/phosphors production. Another relevant application is magnets, which are used in small motors and hard drives, that, for example, use dysprosium and neodymium. When it comes to the mining and extraction of rare-earth elements, roughly 95 per cent of them are extracted in China, which makes EU reliant on imports (EC, 2017b). Furthermore, there is great variations in rare-earth element deposits and sites as well as how these are managed; indeed, in some cases, the working conditions at specific sites can be questionable (EC, 2017b). Another critical raw material where the environmental and working conditions at the deposits are questionable is tantalum which is used in capacitors. Rwanda and Congo are the two largest countries that extract Coltan which is the columbite-tantalite ore refined to tantalum (EC, 2017b; Moran et al. 2014, OECD, 2016).

Plastics make up about 20 per cent of the material used in the production of electrical and electronic equipment; roughly 3.2 million tonnes are used each year by the sector in EU. – 6.2 per cent of the total demand of 52 million tonnes (Raudaskoski et al., 2019). The industry especially uses more expensive engineering plastics such as acrylonitrile butadiene styrene (ABS), polycarbonate/acrylonitrile butadiene styrene (PC/ABS) and high impact polystyrene (HIPS), which have better mechanical and/or thermal properties (Dimitrova et al., 2018). To meet fire safety standards, chemical additivities, such as flame retardants, are used in plastics, some of which can be hazardous especially if the product is made in a country where substance regulations are not as stringent as they are in EU.

Figure 2.12 presents the average compositions of four devices. From the composition graphs it can be concluded that more valuable materials and components are used in high-tech. devices such as smartphones compared to workhorse products such as vacuum cleaners and washing machines.

Figure 2.12 Average composition of smartphones, liquid crystal display televisions, vacuum cleaners and washing machines, per cent by weight

Sources: CECED, 2017; Manhart et al., 2016; Huisman et al., 2007

The Organisation for Economic Co-operation and Development (OECD) has suggested that the global demand for metals for electrical and electronics industry could double by 2060 (OECD, 2019a), with particular growth affecting dysprosium, lithium, neodymium and tantalum which are used in various applications including batteries, magnets and microcapacitors (Marscheider-Weidemann et al., 2016).

When the target metal is extracted from the ground, significant amounts of side material, known as waste rock or tailings, are produced. For example, some individual mines extract in excess 300 million tonnes of waste rock annually along with 80–120 million tonnes of their target ore (UNEP, 2013). In addition to waste rock and tailings, large amounts of water are used. Depending on the ore type and its concentration in ground, several hundred litres of water can be used per kilogram of target metal. Water consumption for mining projects can easily reach an order of gigalitres ([8]) (GL) per year, some even

[8] 1 gigalitre = 10^9 litres

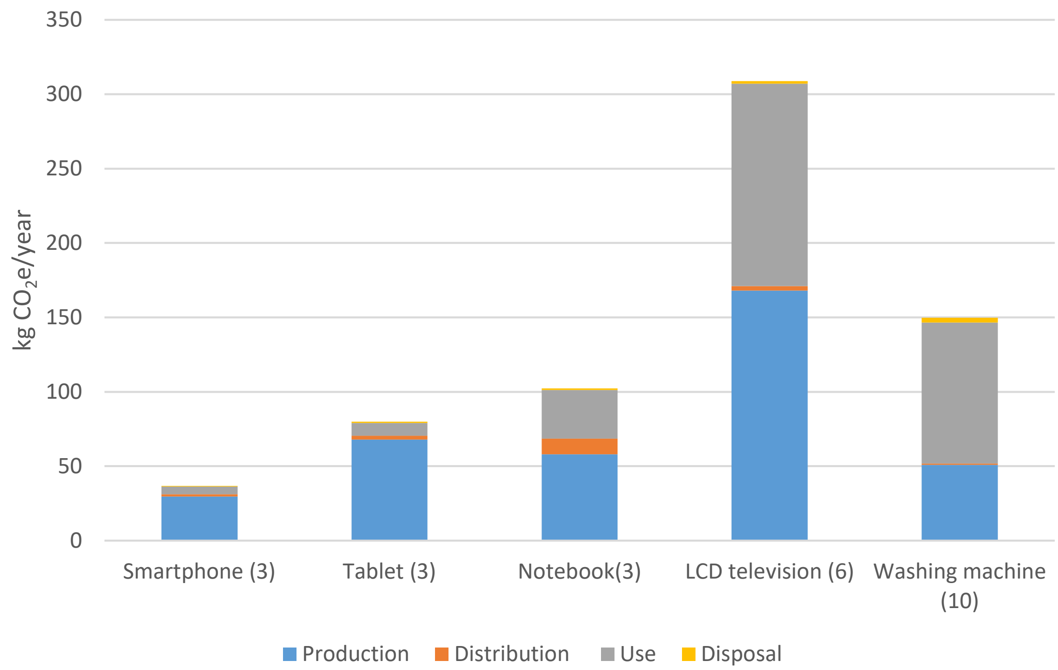
reaching more than 10 GL/year (UNEP, 2013). Both extensive waste generation and water consumption lead to the need for well-managed solid waste and water emission controls, otherwise the consequences can be comprehensive. Unfortunately, this has not always been the case when looking back in history.

2.3.2 Greenhouse gas and other emissions from electrical and electronic equipment

Electrical and electronic equipment cause various environmental impacts throughout their entire lifecycles. The extraction of many raw materials used in electrical and electronic equipment is highly material and energy intensive. As other heavy industries, the mining industry is highly dependent on fossil fuels and therefore has high carbon dioxide emissions. In addition to mining of the raw materials, the production of many components is also material and energy intensive. For example, the production of microchips requires ultra-pure input materials, with large amounts of energy needed for the purification processes.

The use phase of all electrical and electronic equipment requires electricity. The contribution of the different lifecycle phases of electrical and electronic equipment to global warming varies significantly between products (Figure 2.13). For smartphones, for example, the energy used in the production phase accounts for 85–95 per cent of a device's lifecycle annual footprint (Belkhir and Elmeligi, 2018). Lifecycle annual footprint accounts for the annual carbon dioxide footprint of the use phase as well as the energy used in production, depreciating this energy over the useful lifetime of the device. For some devices, such as washing machine, the use phase contributes most of the device's climate impacts (EEB, 2019).

Figure 2.13 Annual greenhouse gas emissions at different lifecycle phases of selected products, kilograms of carbon dioxide equivalent per device per year



Note: The number in brackets refers to the lifespan of the product
LCD = liquid crystal display

Sources: Manhart et al. (2016) for smartphone and tablet; Prakash et al. (2016) for notebook, television and washing machine

Extending product lifetimes usually leads to environmental benefits, because it saves the energy and resources that would otherwise be consumed in manufacturing new products (Bakker and Schuit, 2017). The extension of product lifetime also reduces the generation of waste. According to the EEB (2019), extending the lifetime of all washing machines, smartphones, laptops and vacuum cleaners in the EU by one year would lead to annual savings of around 4 million tonnes of carbon dioxide by 2030, which is equivalent to taking over 2 million cars off the roads for a year. The UN Environment's review of lifecycle assessment (LCA) studies investigated the optimal replacement moment of washing machines, refrigerators, televisions, mobile phones, laptops and vacuum cleaners. The results suggest that washing machines and refrigerators should be used for at least 10 years before they are replaced with a more energy-efficient models, while vacuum cleaners, mobile phones and laptops are typically replaced prematurely and should be used for longer, although it is difficult to suggest an exact replacement moment for these products.

In addition to energy use and climate impacts, the extraction and processing of raw materials for electrical and electronic equipment causes other emissions and pressures, including the generation of emissions to the air, effluents and waste. The manufacturing process of semiconductors releases certain toxic and hazardous gases, organic solvents and particulates. The manufacture of printed circuit boards may release emissions to air including acetic, sulfuric, hydrochloric, nitric and phosphoric acids; chlorine; ammonia; and organic solvent vapors (Babar et al., 2014). Chlorofluorocarbons (CFCs) were used in electrical and electronic equipment for example as refrigerants, but due to their contribution to ozone depletion in the upper atmosphere, the production of CFCs has been phased out under the Montreal Protocol. Mining can also cause soil erosion, which may disrupt natural biological cycles and the flow of nutrients and cause destruction of natural habitats. The extraction of raw materials also uses high amounts of chemicals (Miliute-Plepiene and Youhanan, 2019).

2.3.3 Chemicals use for electrical and electronic equipment

Workers, consumers and society as a whole are exposed to chemicals from electrical and electronic equipment throughout its lifecycle. For example circuit boards, semiconductor chips, cathode ray tubes, coatings and batteries contain metals, such as aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc which may be hazardous. Electrical and electronic equipment may also contain flame retardants, including persistent organic pollutants such as polybrominated diphenyl ethers (PBDEs) (Stenmarck et al., 2017). The industry also utilises different types of chemicals in the manufacturing and packaging processes – more than 500 different chemical substances have been identified in the manufacture of components for electrical and electronic equipment (OECD, 2010). It has also been reported that workers can be exposed to carcinogens and reproductive toxicants during the manufacturing process from such substances as solvents, heavy metals and epoxy resins. During the use phase of electrical and electronic equipment chemical exposure also occurs: in studies on dust from households, increasing levels of dioxins and furans in indoor environments has been observed. (Nimpuno and Scruggs 2011)

In the EU, the Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Directive (2011/65/EC) (RoHs) limits the use of hazardous substances in electronic and electrical equipment with the aim to contributing to the protection of human health and environment. The Directive sets restrictions on the use of cadmium, hexavalent chromium, polybrominated biphenyls (PBBs), lead, mercury and polybrominated diphenyl ethers (PBDEs) in new electrical and electronic products.

An example of a hazardous component in electrical and electronic equipment and how it affects, for example, the end-of-life stage, is the cold cathode fluorescent lamp (CCFL). These were used as a backlight in liquid crystal display (LCD) screens, with roughly 15 tubes mounted behind screens, before the penetration of light emitting diode (LED) technology. The hazardousness of these CCFL tubes originates from mercury which is used in them. This requires special attention in their end-of-life management and proper treatment to ensure the mercury is disposed of safely (Buchert et al., 2012). When a product becomes waste it may still contain several hazardous components, which might have already been banned through, for example, the RoHs Directive, because the length of the product's lifespan. Table 2.1 lists hazardous components and chemicals which have been found from waste electrical and electronic equipment.

Table 2.1 Hazardous components and chemicals in waste electrical and electronic equipment

Component	Substance	Occurrence in e-waste
Halogenated compounds	Polychlorinated biphenyls (PCB) Polybrominated biphenyls (PBB) Polybrominated diphenyl ethers (PBDE) Chlorofluorocarbon (CFC) Polyvinyl chloride (PVC)	Condensers, transformers Fire retardants for plastics Cooling unit, insulation foam Cable Insulation
Radioactive substances	Americium	Medical equipment, fire detectors, active sensing element in smoke detectors
Heavy metals and other metals	Arsenic Barium Beryllium Cadmium Chromium VI Lead Lithium Mercury Nickel Rare-earth elements Selenium Zinc sulphide	Light emitting diodes Getters in cathode-ray tube (CRT) screens Power supply boxes contains silicon controlled rectifiers and x-ray lenses Rechargeable nickel-cadmium (Ni-Cd) batteries, fluorescent layer in CRT screens, printer inks and toners Data tapes, floppy disk CRT screens, batteries, printed circuit boards Lithium-ion (Li) batteries Fluorescent lamps, alkaline batteries Rechargeable Ni-Cd batteries, electron gun in CRT screens Fluorescent layer Older photocopying machines Interior of CRT screens
Others	Toner dust	Toner cartridges for laser printers/copiers

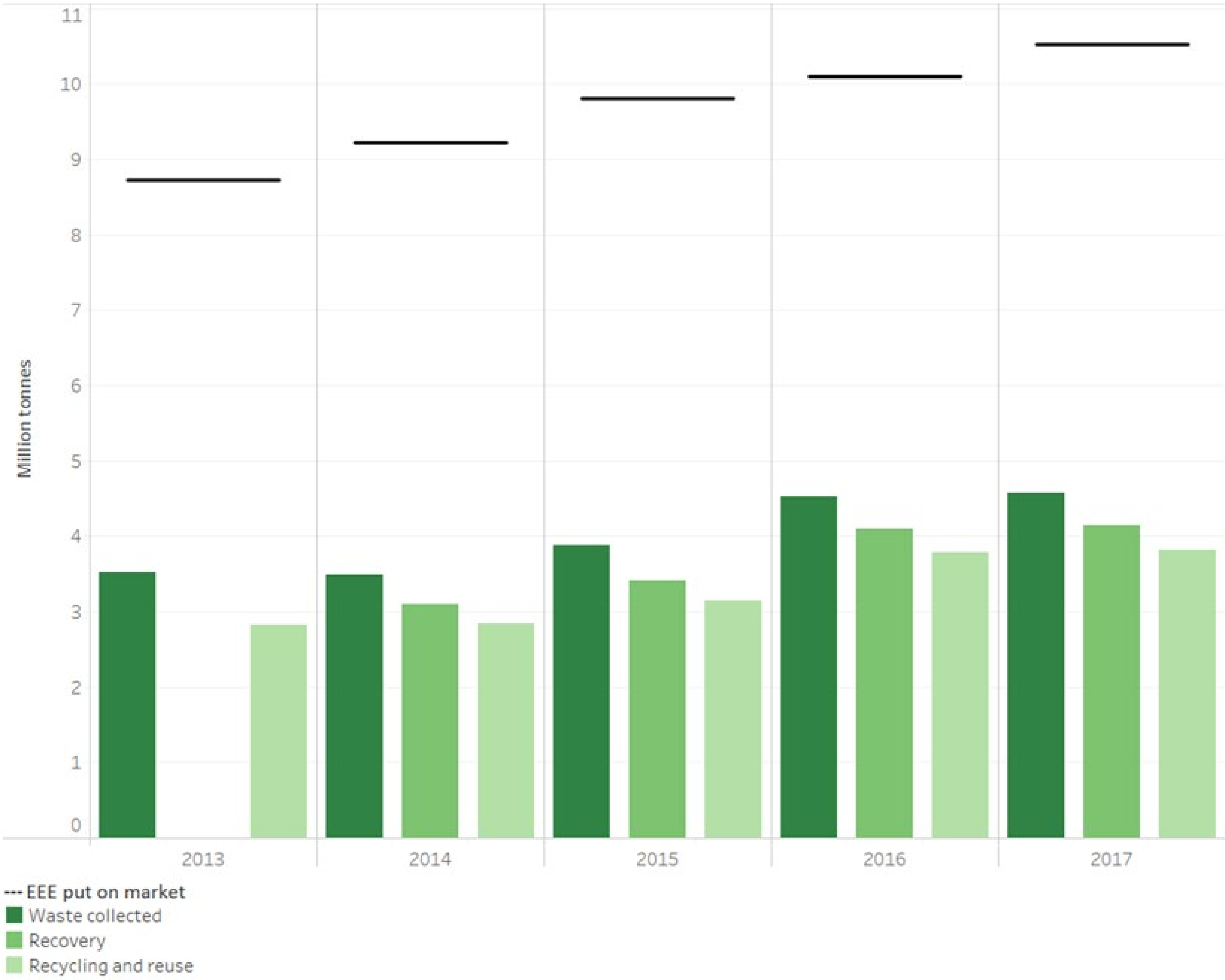
Source: Kumar et al., 2017; Garlapati 2016,

From Table 2.1, it can be noticed that heavy and other metals can be found in different components of electrical and electronic equipment. An old CRT television, which can contain between 0.5 and 4 kilograms of lead depending on the size, is a good example of a device that contains significant amounts of hazardous components which still can be found in the waste electrical and electronic equipment albeit in decreasing quantities (Matharu, 2012). When hazardous components/devices do enter the recycling system, they are separated and treated separately and safely so that valuable materials can be recovered.

2.3.4 Waste electrical and electronic equipment

When electronic and electrical equipment is discarded and enters its end-of-life stage, it become waste electrical and electronic equipment – in 2016, it amounted to approximately 44.7 million tonnes globally. It is one of the fastest growing waste streams in the world, increasing annually by around 4 per cent, and by 2021 the annual amount of waste electrical and electronic equipment is expected to be 52.2 million tonnes. (Baldé et al., 2017) According to Eurostat (2019h), in 2017 around 10.5 million tonnes of electrical and electronic equipment were put on market which converts based on Eurostat guidance to an estimate of roughly 10.4 million tonnes (forthcoming EEA briefing) of generated waste electrical and lelectronic equipment and corresponds to slightly above 20 kg on average per inhabitant in the EU. Roughly 4.5 million tonnes were collected for recovery which present 44 % of the generated waste electrical and electronic amount (Figure 2.14).

Figure 2.14 Electrical and electronic equipment put on the market and waste collected, recovered and recycled/reused, EU, 2013/2017, million tonnes



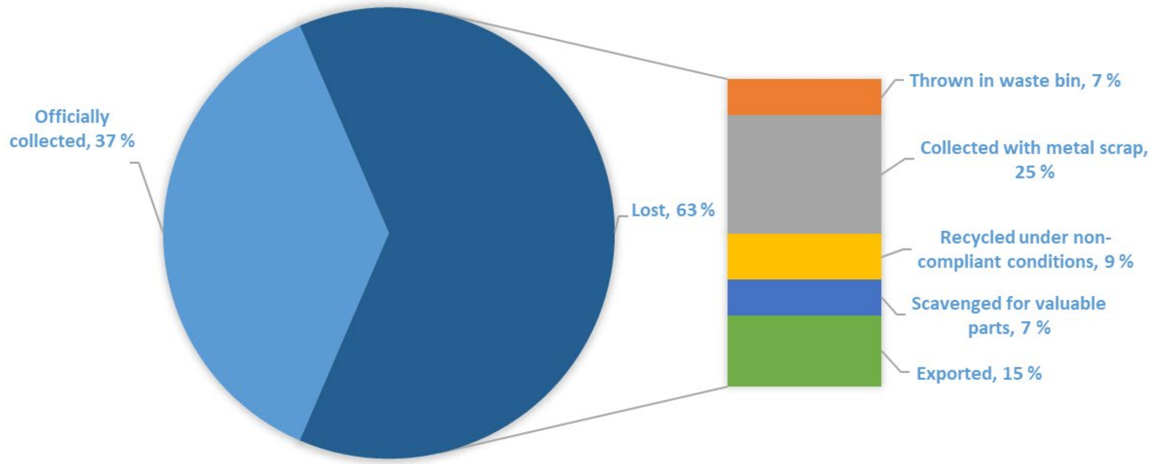
Source: Eurostat, 2019h

When comparing the trend in Figure 2.14 with the waste management hierarchy established by the EU's Waste Framework Directive (2008/98/EC) which prioritises the prevention of waste generation followed by preparation for reuse and recycling, and finally disposal, there are mixed trends on the transition towards a situation in which the hierarchy is respected for waste electrical and electronic equipment. The minimum target for collection is set at 45 % for reference year 2016 (as reported in 2018) and will rise to 65 % for reference year 2019 (to be reported in 2021) as stated by the waste electrical and electronic equipment directive (Directive 2012/19/EU). In the EU in 2016 the collection rate of waste electrical and electronic equipment was 49 per cent. This share is calculated as the ratio of the amount of collected waste electrical and electronic equipment in 2016 in relation to the average amount of electrical and electronic equipment put on the market in the three preceding years, 2013-2015. To comply to the minimum target for collection of 65 per cent, Member States should move to better performing collection systems in combination with sound monitoring (and hence prevent for having leakage of waste electrical and electronic equipment). When waste electrical and electronic equipment is collected, however, a high share of it, in terms of mass, is recovered and recycled, suggesting that, when applied to the waste the recycling system is highly efficient.

In a detailed study Huisman et al. (2017) assessed where waste electrical and electronic equipment ended in the EU in 2015 (Figure 2.15). Roughly 37 per cent of which was collected through an official take-back system. Apparently, significant quantities of waste electrical and electronic equipment ended up in sites that may not be equipped and appropriate for treatment (Huisman et al., 2017). This is critical as an example from US show that, while waste electrical and electronic equipment may only represents

2 per cent of solid waste streams, it can represent up to 70 per cent of the hazardous waste that ends up in landfill (World Economy Forum, 2019). In addition, more than 1.5 million tonnes of undocumented of discarded electronic products are exported from the EU, and a further 0.75 million tonnes are thrown into the waste bin or collected together with mixed waste (Huisman et al., 2015).

Figure 2.15 The destiny of waste electrical and electronic equipment in EU, 2015



Source: Author's compilation based on data from Huisman et al., 2017 and Huisman et al., 2015

Today, recycling of waste electrical and electronic equipment focuses on the recovery of metals such as aluminum, copper, gold, silver and steel,. The recycling rate of these metals from all types of waste is above 50 per cent (UNEP, 2011) thanks to the availability of well-established industrial processes in the EU. At the moment, however, proper recycling infrastructure for other metals found in electrical and electronic equipment, such as gallium, indium and rare-earth metals, are lacking resulting in recycling rates below 1 per cent. Additionally, waste electrical and electronic equipment contains significant amounts of plastics which can contain hazardous substances such as flame retardants. Some of these harmful substances are classified as persistent organic pollutants (POPs) which require appropriate and safe disposal (Stockholm Convention, 2006;). Even though restrictions on the use of POPs in new items were implemented in the EU some time ago, electrical and electronic equipment manufacturer beyond its borders containing some of these substances can still enter Europe through individual consumer's online shopping.

In addition to flame retardants in plastic, waste electrical and electronic equipment can contain various hazardous susbtances, for example, halogenated compounds such as polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) , and heavy metals, such as antimony, cadmium, lead and mercury (Kumar et al., 2017). These hazardous components can pose a threat to the environment and human health if waste electrical and electronic equipment is disposed of improperly or recycled in informal conditions.

When considering the lifetimes of products and their effect on waste, depletion of materials and waste generation tend to decrease when the lifetime of a product is increased. Designing long-lasting products is a key strategy that saves materials and also reduces the amount of end-of-life waste (Cordella et al., 2019). In an interview, it was stated that 8–10 per cent of the electrical and electronic equipment brought to civic amenity sites managed by municipalities and/or waste companies can potentially be reused, as long as it is handled correctly. (Watson et al., 2017)

3 Case studies

3.1 Smartphones

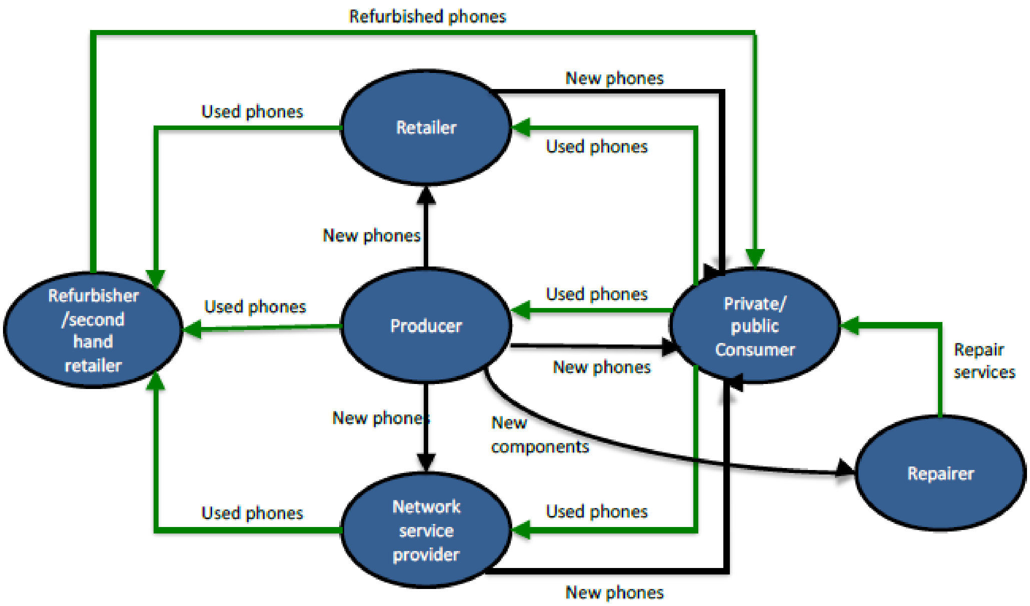
3.1.1 Overview

Smartphones, which have largely replaced basic mobile phones but also function as cameras, global positioning systems (GPS), MP3 players, calculators and voice recorders, well reflect 21st century society and are considered fashion electronics or up-to-date products. They first came on to the consumer markets in the late 1990s but really gained popularity with the launch of the iPhone in 2007 (Statista, 2018a). By 2014, two out of every three mobile phones shipped globally were smartphones (Watson et al., 2017).

The variety of models, number of suppliers and market for smartphones grew and developed steadily until 2016, after which became mature, with slightly more than 1.5 billion being sold globally to end users in 2018 (Statista, 2019b). Western European sales peaked in 2015 at 135 million units since then they have decreased by between 3 to 4 per cent annually – roughly 125 million units worth some EUR 50 billion were sold in 2017. In Central and Eastern Europe, however, sales shown no signs of maturing: in 2017 around 85 million units worth EUR 18.7 billion were bought. (Statista 2018b,c,d,e) More than 90 per cent of mobile phones sold in EU are imported, mainly from China and other Asian countries (Eurostat, 2019d).

The smartphone industry consists of many key actors who provide either services or hardware products (Figure 3.1). Mobile phone manufacturers, who have a direct influence on the design and servicing of the devices, are the core actors. Some of these manufacturers are also software producers, along with application producers and other digital providers, who provide, for example, updates to software along the phone's lifetime. Other relevant actors that influence, for example, customer activity and business models, are retailers, network service providers, mobile phone repairers and refurbishers and second-hand retailers (Cordella et al., 2019).

Figure 3.1 Relationships between actors in the smartphone value chain



Source: Watson et al., 2017

Globally, the average selling price of smartphones decreased from EUR 335 in 2012 to EUR 270 in 2015 and then rose slightly increase to EUR 287 in 2017 (Statista, 2018f). In Europe the average selling price was estimated to be around EUR 320 in 2017 (Cordella et al., 2019). For second-hand smartphones, the worldwide average value was estimated to be around EUR 124 in 2016 (Watson et al., 2017). Like for the majority of new consumer items, most value is lost in the first year after which depreciation slows down. It has been estimated that the residual value could, on average, be: 54 per cent of the original price for a 1-year old product; 32 per cent after 2 years; 20 per cent after 3 years. After 4– 5 years trade-ins was not considered economically interesting (Cordella et al., 2019).

Looking at the cost of smartphone components, the display is the most expensive, representing slightly above 20 per cent of the total cost; followed by the apps/baseband processor, 17 per cent; and mechanical components, 12 per cent. Some manufacturers also reported repair costs for displays, the cost of which can vary from 15 to 40 per cent of the original purchase price (Cordella et al., 2019).

3.1.2 Product lifetime

Smartphones are used more than any other device, and as a result they have taken the central stage in consumers' lives. They are no longer used as much for making voice calls – for which they were primarily designed – but more for other functions such as browsing the internet, taking and sharing photos, gaming, emails and social media (Cordella et al., 2019). For the phone to operate with the newest versions of the applications, which are used for the main functions, it needs to be up-to-date in terms of hardware and software. This often leads to a situation in which a smartphone is replaced before it is broken. In recent literature, the most common reason for replacing a smartphone was "wanting the latest phone model", 47 per cent; followed by "existing phone is not functioning", 40 per cent; and "wanting the latest software", 13 per cent (Watson et al., 2017).

The average upgrade cycle of smartphone hardware has been increasing to slightly less than two years but, according to some literature, the average lifetime may even be three years (EEB, 2019). In 2013, the average smartphone lifetimes in France, Germany, Italy, Spain and the UK were around 18.3 months, rising to 21.6 months in 2016 (Cordella et al., 2019). No direct reasons for the increase have been reported, but perhaps the slower speed of innovation might explain it (Cordella et al., 2019). High purchase prices for devices with no new revolutionary functions may have postponed purchase decisions. Since the common reasons for purchasing a smartphone are often behavioural, driven by launches of new models and features as well as social expectations, the designed lifetimes of smartphones are seldom reached. (Watson et al., 2017)

When looking at the reasons behind the change in lifetimes, information on the technical aspects has been presented. In a recent survey (OCU, 2018) it was reported that 47 per cent of faults occurred during the first two years of use while an additional 39 per cent occurred between the second and third year. The highest number of problems was related to the battery, 42 per cent; and to the operating system, 14 per cent. (Cordella et al., 2019) In 2013, 43 per cent of product failures were reportedly the result of the device being dropped on a hard surface and 35 per cent because of contact with water (Watson et al., 2017), however, these statistics may not represent the situation for current technologies and design.

Although different from failure data, indirect information about limiting factors can be gathered from repair statistics. On a German repair platform, statistics on failures and repairs for common smartphone models have been published. Screens appear to be the most frequently repaired part, with repairs of back covers becoming an issue for more recent models. The batteries, the duration and performance of which over time can affect the lifetime of the smartphone, have had a change in the design and are currently designed to last longer in terms of charging cycles so that replacement is required less frequently. This has also caused a significant decline in battery repair services for more recent models relative to older ones. Another important factor that can affect the functional lifetime of smartphones is the ending of the software support period offered by manufacturers, which is usually two years or more (Cordella et al., 2019).

3.1.3 Environmental and climate impacts

As previously mentioned, smartphones are complex devices which may contain up to 60 different elements from the periodic table. Besides basic metals such as aluminum, copper, steel/iron, precious metals such as palladium, gold and silver as well as rare-earth elements, tantalum and cobalt, which have been classified as critical raw materials by the EU, are used (Manhart et al., 2016). In the production and mining of some of these critical raw materials and precious metals, environmental and societal impacts have been reported.

When looking at greenhouse gas emissions, a considerable number of lifecycle analyses have been carried out on smartphones. The studies gathered by Manhart et al. (2016) show a wide range of estimated greenhouse gas emissions (16–110 kilograms of carbon dioxide equivalent) over the lifetime of different smartphone models. When comparing the greenhouse gas emissions from smartphones with other products, such as desktop computer, televisions and washing machines, the environmental impact at the individual product level is modest. It is the massive total sales volume which causes the high environmental impact of these products, mainly caused by their manufacture (Manhart et al., 2016). In fact, the production phase accounts for 35–92 per cent of the total greenhouse gas emissions of smartphones (EEB, 2019; Manhart et al., 2016). In manufacture, the LCD screens contribute most to these emissions, followed by integrated circuits and printed circuit boards. The use phase, which generally includes the emissions linked to electricity consumption from charging the smartphones at the premises of end-consumers, was found to contribute about 10–49 per cent of the total lifetime greenhouse gas emissions. The distribution phase is responsible for 3–17 per cent of the emissions, while the contribution of the end-of-life phase was found to be negligible. (Manhart et al., 2016) If the energy required to manufacture all smartphones since 2007 is considered, roughly 968 terawatt ([10]) hours were used, which nearly corresponds to India's annual electricity consumption in 2014 (Jardim, 2017).

Since the greenhouse emissions are mostly generated during the manufacturing phase, lifetime extension should be supported as much as possible. From an environmental point of view, smartphones should be kept in use as long as possible. Different studies have reported that smartphones should ideally be used from 7–20 years (EEB, 2019; Bakker and Schuit, 2017). To give an illustration, a 1-year lifetime extension of all smartphones in Europe would safe 2.1 million tonnes of carbon dioxide per year by 2030: in other words, a reduction of the overall carbon footprint from smartphones of 31 per cent, the equivalent of taking more than 1 million cars off the road for a year (EEB, 2019). Extending a smartphone's lifetime by 4.5 years could halve its impact. It has also been reported that with one year extension of a smartphone's lifetime, 27 per cent of its primary energy consumption could be saved along with 29 per cent of its water consumption (Benton et al., 2015).

3.1.4 Measures

Smartphones can be considered as fashion electronics. Because of their short lifecycles and the considerable environmental impacts of their manufacture, opportunities to increase their lifetimes through new business models and policy action are highly desirable. There are several possible business models and measures, some of which are discussed in more detail below.

3.1.4.1 Increase durability

By increasing durability, the functional/designed lifetime of a product can be extended. For smartphones, a number of measures, such as protection from water and dust, resistance to accidental drops, improved battery life and support for updating the operating systems have been identified as promising measures (Cordella et al., 2019). From a business model approach, increasing product durability could generate additional revenues later in the device's life cycle through the creation of services.

[10] 1 terawatt = 10^{12} watts

3.1.4.2 Repairability and refurbishment

The refurbishment and repair of smartphones has become a service which is growing. While repair has mainly focused on devices which are still in use, some positive indications of the repair of second-hand devices have emerged. Repair businesses state that the growth in the second-hand market has potential for a factor 5 to 10 increase but is being held back by a lack of awareness among consumers (Watson et al., 2017). Modularity of devices, the supply and cost of spare parts, repair guides, standards for durability and repairability as well as data deletion have been identified as ways of promoting the repair and refurbishment of second-hand devices (Cordella et al., 2019, Tröger et al., 2017).

According to Watson et al. (2017), repair could be worthwhile even 3–5 years after sale. There is, however, a huge variation in the cost of repairs since many devices do not have easily removable batteries or replaceable screens. Repair costs are in particular a barrier for screens – a screen can cost up to a 40 per cent of the product's original price and they are rising for more recent models. One interesting promotion mechanism could be a reduction in value added tax (VAT) or tax breaks for repair, refurbishment and resale. This could partially redress the economic imbalance and accelerate growth (Watson et al., 2017).

3.1.4.3 Policy

To facilitate the repair and resale of second-hand devices, clarifications surrounding the ownership and treatment of waste electrical and electronic equipment would be beneficial. Currently ambiguity in the definition of discarding an appliance may have led to situations through which a smartphone is treated as waste rather than being repaired. Once an object has been discarded, for it to cease being waste it usually needs to undergo procedures, which can range from the relatively simple to something quite extensive and complex and may include both waste and product regulations such as warranties and product safety. It could be beneficial to make a distinction between reuse as a waste prevention measure on the one hand, and reuse following a material recovery process on the other (Watson et al., 2017).

Introducing lifespan labelling has shown positive indications towards purchasing decisions. In a study by the European Economic and Social Committee it was noted that sales of products that have a lifespan label increased 13.8 per cent. Testing on smartphones showed a sales increase of 11.4 per cent (EESC, 2016).

The minimum legal guarantee for new products set by the Consumer Sales and Guarantees Directive (1999/44/EC) is two years with allowances for Member States to increase this. Extending the minimum legal guarantees would prolong the period over which sellers financially support repair services (Tröger et al., 2017) and could encourage producers to engage in design-for-repair and longer lifetimes. Some weaknesses have, however, been identified, such as low consumer awareness of minimum guarantee periods and reduced likelihoods of winning a claim after the first six months since after that the consumer has to prove that there was a fault in the phone (Watson et al. 2017).

3.2 Washing machine

3.2.1 Overview

Household washing machines are very common – on average, 92 per cent of European households have one, and in 2015, there were 201.4 million units in use. Each family uses its washing machine, on average, 200 times a year or 3.8 times per week; this number has not grown significantly in the past 5 years (Boyano et al., 2017), indicating relatively stable customer needs.

Consumers typically replace their washing machines when the old one breaks (HOP 2019; Cox et al., 2013). When buying a new machine, the most important factors influencing a consumer's choice are price, and energy and water efficiency (Boyano et al., 2017). In 2019, the average price of a washing machine in Europe was EUR 368, a decrease by 3.7 per cent compared with 2012 (Statista 2019c). The operating costs, however, are significant – water and energy costs for a typical energy-efficient washing machine amount to EUR 989 over 15 years (Topten, 2019), but switching to one of the most energy-efficient washing machines could save EUR 250 over the lifetime of the product. This partly explains why energy and water efficiency is the second most important factor in consumers' purchasing decisions (Boyano et al., 2017). The European Commission guides consumers' purchasing decision by requiring new washing machines to carry an energy label showing their energy efficiency rating (European Commission 2019a).

The washing machine value chain has the following key actors: manufacturers, retailers, the maintenance and repair sector, rental/leasing actors, and the waste management enterprises. The manufacturers and retailers are the key players in terms of monetary value. Annual sales are expected to remain almost stable at approximately 13.1 million units per year (Boyano et al., 2017). It should be noted that 16 per cent of the washing machines sold in EU was imported from third countries (Eurostat 2019d).

As the market is almost saturated, product innovation is a necessity in today's sales-oriented market as an incentive to replace existing machines. The main technical advancement in recent years includes improved energy and water efficiency, increased speed and loading capacity, as well as smart technology. With this smart technology consumers can, for example start, monitor and stop cycles from their smartphone, and manufacturers can run diagnostics on the washing machine from afar, notifying consumers when a problem occurs.

3.2.2 Product lifetime

Washing machines are designed for a specific service life or number of cycles. This planned parameter (designed lifetime) serves as a guide to product designers and developers. For example, a washing machine designed for 2000 cycles is supposed to last for 10 years if it runs 200 wash cycles per year on average (Prakash et al., 2016). In fact, the actual lifetime of washing machines has decreased over recent years. In France, the average first-use duration of the washing machine has decreased from ten to seven years between 2010 and 2018 (HOP 2019). In a study by Wieser (2015) the actual lifetime of a washing machine was reported to be 8.3 years. It is important to note that the actual product lifetime is lower than consumers expectation: an EU study shows that consumers expect a washing machine to last for 12.5 years (Boyano et al., 2017).

Why has the service life of washing machines shortened, or why are old washing machines not used or wanted anymore? A HOP survey (2019) of French consumers showed that 84 per cent of consumers replaced their washing machines because of product failure or dysfunction (absolute obsolescence), 13 per cent due to moving house or other family events, and 3 per cent because they wanted a new product (relative obsolescence).

As the majority of washing machines are replaced because of mechanical breakdown, it is worth investigating which parts or components fail most frequently and why they are not repaired. The ones with the most common recurring failures are the electronic parts, 14 per cent of all cases; shock absorbers and bearings, 13.8 per cent of all cases; doors; and carbon brushes (Tecchio et al., 2016).

Almost exactly 50 per cent of the broken electronics and just more than 76 per cent of the broken bearings are not repaired, making the machines unusable, due to poor repairability or high cost. For example, the cost for repairing electronic parts is high, EUR 200 on average, especially as the boards are often placed in a clipped box that is hard to access, and the technical diagrams of the boards are only accessible by a few authorised repairers. In 50 per cent of cases, the repair option was declined, and consumers replaced the entire machine (HOP 2019). Another determining factor for consumers in deciding whether to repair their washing machine is the time needed for the repair as the frequent use of the washing machine makes them indispensable in most households (EC, 2018a).

Apart from mechanical obsolescence, attention should be drawn to the early replacement of a functioning washing machine. In Germany, more than 10 per cent of the washing machines disposed at municipal collection points or recycling centres in 2013 were only 5 years old or less, up from 6 per cent in 2004 (Tecchio et al., 2016). Similarly, DARTY's After-sales Service Barometer shows that 13 per cent of the customers replace their washing machines while the old one is still working (Darty 2018).

Research with focus groups has shown that large household electrical and electronic equipment, such as washing machines, are considered as workhorse products and thus important investments for consumers (EC, 2018a). Because of this and combined with the fact that washing machines are currently less dependent on fashion trends, durability of washing machines is considered highly important. According to a study done by the Waste and Resources Action Programme (WRAP), consumers are even willing to pay up to 30 per cent more for a washing machine that is backed by a longer standard warranty (WRAP, 2013).

3.2.3 Environmental and climate impacts

From an environmental and climate point of view, the use phase of a washing machine has the highest lifecycle impact of up to 75 per cent depending on the type and specifications of the device. The non-use impact – manufacturing, distribution and disposal – accounts for the other 25 per cent (EEB, 2019).

The impact of the use phase is mainly determined by energy and water use. In the last decades and years, washing machines have become more efficient and as a result most product models on the European market achieve the highest class, A+++, even though the EU Energy Label Class has been improved several times. However, the optimised water and energy programmes designed to achieve the highest energy labelling class are not always used by consumers (Bracquené E. et al., 2018). Consumer behaviour, such as the wash load, the amount and type of detergent or choice of programme, are important determining parameters. For countries with a relatively low-carbon electricity mix, variability in lifecycle greenhouse gas emissions is mainly determined by laundry product-related parameters (Shahmohammadi et al., 2018).

The main materials used in a typical washing machine are (stainless) steel; plastics, mainly polypropylene (PP); cast iron and concrete. Although the material composition can vary depending on the type of machine, the global warming potential (GWP) of the materials, PP has the highest global warming potential GWP, 37–40 per cent of the total, followed by the printed circuit board at 18 per cent (ETH, 2011).

As the use phase has the highest impact, there is a potential trade-off between a longer lifetime and an improved new product with better energy and resource efficiency (Bakker and Schuit, 2017). Nonetheless, various studies show it is environmentally beneficial to extend lifetimes beyond typical actual lifetime. An EEB study (2019) shows that, to compensate for the greenhouse gas emissions from production, distribution and disposal, and given at normal energy-efficiency improvement rates, the minimum optimal lifetime of a washing machines is 17 years. A United Nations Environment Programme (UNEP) study shows that it only makes environmental sense if a washing machine is replaced after 10 years and if the new model is significantly more energy efficient (Bakker and Schuit, 2017).

Extending the lifetime of all washing machines in the EU by one year would save 0.25 million tonnes of carbon dioxide per year by 2030, as the non-use impact would be spread over the longer lifetime (EEB, 2019).

3.2.4 Measures

3.2.4.1 Durability and business models

Ecodesign for better durability: in general, manufacturers can improve the durability of their product through materials selection and high-quality components. A different design might also improve repairability. If all washing machines, as some are, were designed in such a way that bearings were fixed to the plastic or metal tub with screws, disassembly and the replacement of bearings would be easier and less expensive. If fuses were not soldered to the electrical board and made easier to replace, fixing failures caused by power surges would cost much less (Tecchio et al. 2016).

Pay-per-use business model: some companies offer a pay-per-use business model for washing machines, which means they offer the customers the free installation of high-quality models and servicing if the appliances need to be repaired or replaced. The business model is tailored to reduce waste due to the benefit of long-lasting machines that can be upgraded.

3.2.4.2 Repairability

Repair package and do-it-yourself (DIY) guidelines: to help consumers repair rather than replace broken household appliances, some enterprises offer a repair service package for individuals together with a manual to help consumers repair their washing machine themselves.

3.2.4.3 Policy

Ecodesign requirements: on 1 October 2019, the European Commission adopted new ecodesign measures for washing machines. For the first time, these include requirements for repairability and recyclability, thereby aiming to contribute to circular economy objectives by improving the lifespan, maintenance, reuse, upgradability, recyclability and waste handling. (EU regulation 2019/2023).

Purchasing decision assistance: as of January 2020, France has made it mandatory to display the repairability index of electrical and electronic equipment. Furthermore, France plans to support an initiative to make the harmonisation of information on repairability a European Community obligation (MTES, 2018).

Extended product warranty: the Danish Consumers Council has proposed extending the consumer warranty of large consumer goods, such as washing machines, from two to five years (Lauridsen and Jørgensen, 2015).

3.2.4.4 Consumer communication and behaviour

Because the use phase is the main contributor to the environmental impact of washing machines, communications for consumers about their optimal use – wash load, programme, amount of detergent, etc. – would be beneficial. Washing machines with built-in smart technology could help consumers to monitor and optimise use.

Shared washing machines in buildings: apartment buildings in Sweden and Finland, amongst others, are normally equipped with a communal laundry rooms, with more durable washing and drying facilities. Such shared facilities are made available at no extra charge to everyone living in the apartment block.

3.3 Vacuum cleaners

3.3.1 Overview

Vacuum cleaners are made in a variety of shapes and models for domestic and non-domestic use and are categorised as small household appliances. The four main types are cylinder, upright, handheld and robot cleaners. Although the types can have different power sources – mains electricity, batteries or can be powered by both (hybrid) – and dust receptacles – removable bag or bagless – the EU's ecodesign requirements for vacuum cleaners does not differentiate between types and only applies to mains-operated and hybrid dry vacuum cleaners. Battery operated and robot vacuum cleaners are currently exempted from the Ecodesign (666/2013) and Energy Labelling Regulation (665/2013) (EU, 2013).

The four main types are described below, using the terms and definitions used in the regulations and harmonised standard EN 30312-1:2017 and as used in the Review study of ecodesign and energy labelling for vacuum cleaners (EC, 2019e).

Cylinder vacuum cleaner: a vacuum cleaner with the cleaning head separated from the vacuum generator (fan) and dirt storage facility, usually by means of a flexible hose. This type of cleaner is pulled around by the user during cleaning and designed for cleaning carpets and hard floors. They can be either bagged or bagless.

Handheld vacuum cleaner: a lightweight vacuum cleaner with cleaning head, dirt storage and vacuum generator integrated in a compact housing allowing the cleaner to be operated whilst being held in the hand. They are usually cordless and rechargeable.

Upright vacuum cleaner: a self-standing and floor-supported vacuum cleaner with the cleaning head forming an integral part of or permanently connected to the cleaner housing, the cleaning head normally being provided with an agitation device to assist dirt removal and the complete cleaner housing being moved over the surface to be cleaned by means of an attached handle. They can be either bagged or bagless.

Robot vacuum cleaner: a battery-operated vacuum cleaner that is capable of operating without human intervention within a defined perimeter, consisting of a mobile part and a docking station and/or other accessories to assist its operation.

The European market of vacuum cleaners for dry and wet vacuum cleaners, with and without self-contained electric motors and with a maximum dust capacity of 20 litres, is a mature one which grew on average by 0.72 per cent a year between 2014 and 2018. 48.07 million devices were sold in 2018, and this is expected to grow to 50.31 million by 2023. Penetration per person has been steady for the past five years, 2014–2018, and is expected to remain at 0.06 per person until 2023 (Statista, 2019d). With a total stock of 269 million household vacuum cleaners (EC, 2019e) and around 222 million households in the EU (Eurostat, 2019j), the penetration per household in 2018 was 1.2.

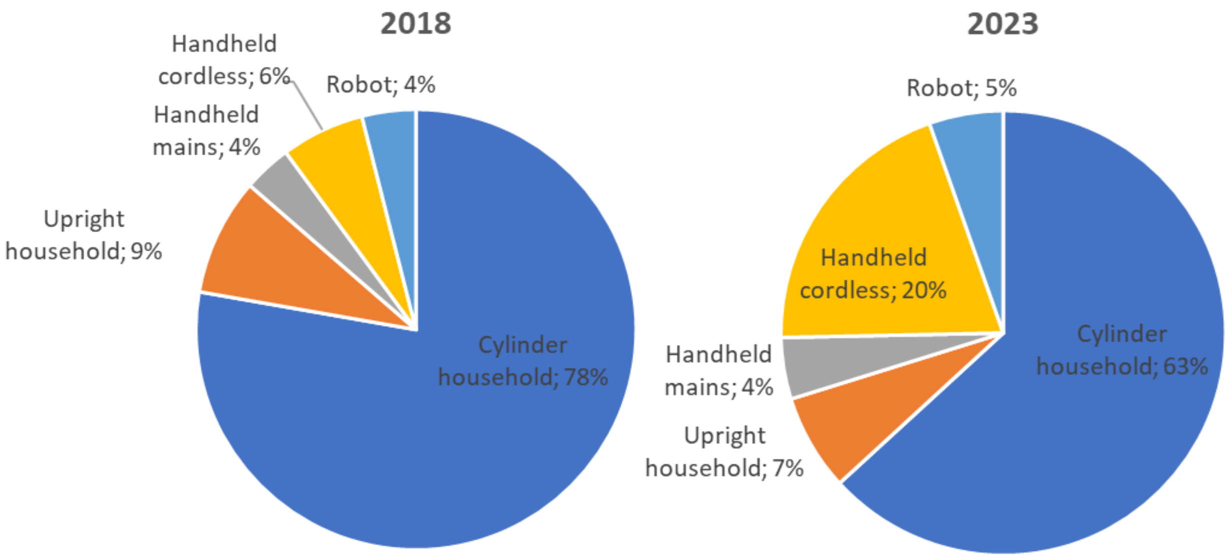
The average price per vacuum cleaner in Europe was EUR 128.32 in 2019, an increase of just 1.6 per cent compared to 2010 (Statista, 2019d). The small increase is likely a result of the implementation of the Ecodesign Regulation and the annulled Energy Labelling Regulation which caused a shift in design criteria from high to low wattage and high dust pickup (EC, 2019e). Due to the saturation of the market and price competition, however, the price increase was negligible. In the coming years, with the increased popularity of more expensive cordless handheld and robot vacuum cleaners, the average price per unit is expected to increase slightly.

The total European market for vacuum cleaners is expected to have a compound annual growth rate of 1.2 per cent from 2018 until 2023 (Statista, 2019d). Although robot vacuum cleaners only accounted for

4 per cent of total sales of domestic vacuum cleaners in the EU in 2018 (Figure 3.2), they were the fastest growing type (EC, 2019e). As a result of the rising demand for artificial intelligence (AI) and internet of things (IoT) enabled home appliances (Fortune Business Insights, 2019) that offer greater convenience to the growing number urban consumers living hectic lives, the adoption of robot vacuum cleaners over the traditional cylinder and upright cleaners is expected to increase further.

In the coming years, however, cordless handheld vacuum cleaners are expected to be the fastest growing type, and exceed the sales of cylinder vacuum cleaners, currently the prevalent type, by 2028 (GfK, 2016). Most consumers buying a cordless vacuum cleaner do so with the intention of using it for small cleaning jobs, but end up using it as their main one (EC, 2019e).

Figure 3.2 EU market share of vacuum cleaner sales, by type (totals do not sum due to rounding)



Source: EC, 2019e

The domestic vacuum cleaner market is supplied by a large number of companies. While cordless and robot vacuum cleaners are produced by established brands, the robot vacuum cleaner market is largely dominated by specialised manufacturers. The majority of vacuum cleaners are manufactured in China or other Asian countries, where many of the large companies have their own production facilities. Others add their branding to devices produced by from original equipment manufacturers (OEMs). There are no small and medium-sized enterprises (SMEs) making domestic vacuum cleaners in the EU (EC, 2019e).

As vacuum cleaners are sold through traditional retail channels, retailers are key actors in the value chain. Offline, the position of large retail chains is increasingly dominant while online sales of small domestic appliances, including (robot) vacuum cleaners, are increasing rapidly (GfK, 2016). Other relevant actors in the value chain are repair and maintenance service providers and waste management companies. Although few repair shops for vacuum cleaners exist, except those who handle warranty repairs, most repairs, other than internal repairs, can be carried out by the end-user (EC, 2019).

3.3.2 Product lifetime

The actual lifetime of domestic vacuum cleaners ranges between 6.3 and 10 years, with an average lifetime of 8 years (AEA, 2009). Because cordless and robot vacuum cleaners are relatively new to the market, no figures on their average lifetime are available. However, it is expected that due to the presence of a rechargeable batteries in both types, their average lifetimes will be shorter than 8 years. Replacement batteries for most cordless and robot vacuum cleaners are readily available. If the device has a lithium-ion (Li-ion) battery, it will have to be replaced every 2–3 years at a cost of EUR 80–100 for

Li-ion, but if it runs on a nickel metal hydride battery (NiMH), that will may have to be replaced in half the time but at half the cost (EC, 2019e).

Robot vacuum cleaners are more complex, using small parts and technologies such as sensors and cameras that also might decrease their expected lifetimes. The 2019 Review Study on Vacuum Cleaners assumes a 6-year lifespan for cordless and robot devices, with a standard deviation of 3 years. As all types become more sophisticated, printed circuit boards will become more important key components, increasing the likelihood of a failure occurring during the lifetime of the vacuum cleaner (Bracquené, 2018).

Standard mains-operated domestic vacuum cleaners have average expected lifetimes of 10.3 years, which indicates that consumers expect them to last longer than they actually do (Wieser et al., 2015).

The motor is regarded as critical component, as motor failure usually leads to the disposal of the vacuum cleaner (AEA, 2009). Motors of vacuum cleaners typically rely on carbon brushes to supply electrical power to the rotating armature. There is a relationship between the length of the carbon brushes and the product lifetime of the motor, as these brushes tend to wear down with use. At the end of the carbon brush life, the vacuum cleaner is currently replaced (Bobba et al., 2016). This issue could be avoided by using new generations of electrical motors without carbon brushes (AEA, 2009). These motors are 5–9 times more expensive than universal motors with carbon brushes, but have a life of 3,000–10,000 hours or more (VHK, 2016).

The Ecodesign Regulation for vacuum cleaners requires motor lifetimes of at least 500 hours, which the great majority of mains-operated vacuum cleaners currently on the market achieve (Consumentenbond, 2017). Both the Energy Labelling and the Ecodesign Regulation implementing measures for vacuum cleaners assume 50 one-hour cleaning tasks per year. Assuming a 500 hour lifetime of the motor, this corresponds to a 10-year lifetime for the device, which is higher than the current average lifetime of eight years, suggesting that motor failure is not the main reason why consumers replace their vacuum cleaners.

According to various consumer surveys, a split or broken hose is a major source of complaints, accounting for 7–15 per cent of recorded faults (Bracquené, 2018). In addition to durability requirements for the motor, the Ecodesign Regulation also includes durability requirements for the hose. This should still be usable after 40,000 oscillations under strain (EU, 2013). In general, replacing a hose is easy and spare parts are adequately available (EC, 2019e).

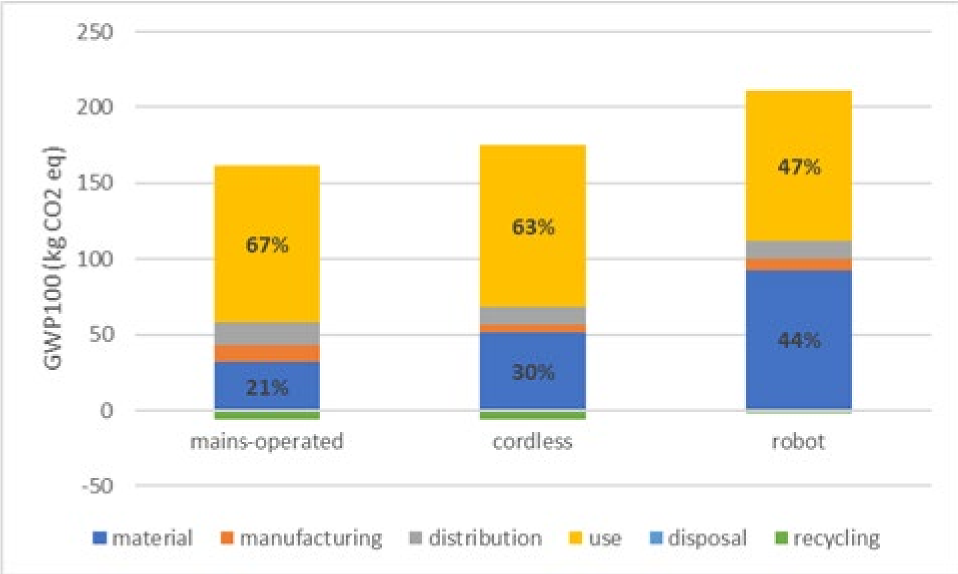
Next to failures related to suction (the motor) and the hose, belt, power cable and blocked filters are common failures reported by consumers (JRC, 2015). As filters should be changed regularly, blocked ones suggest a lack of maintenance done by the consumer (Bracquené, 2018). Since excess amounts of dust and particles can clog the vacuum cleaner, blocking the airflow, regular checks and maintenance done by the consumer should limit breakdowns.

According to consumer surveys reported in Behavioural Study on Consumers' Engagement in the Circular Economy (EC, 2018a), 41 per cent of the participating consumers indicated they had not repaired their vacuum cleaner the last time it broke down or became faulty. The most important reasons for not repairing it are the cost, 36 per cent, and preferring to buy a new device, 33 per cent. Fashion or relative obsolescence was indicated to play a role as well, 20 per cent.

3.3.3 Environmental and climate impacts

Vacuum cleaners are responsible for 0.79 per cent of the total EU electricity consumption and 0.21 per cent of the total EU emitted greenhouse gases. Although the energy consumption in the use phase has decreased over the past years, it still accounts for 71 per cent of a device's total lifetime energy consumption. The material phase is responsible for 20 per cent of the energy consumption for mains-operated vacuum cleaners (EC, 2019e).

Figure 3.3. Total emissions from different types of vacuum cleaner over a lifetime, by phase



Source: EC, 2019e

The energy consumption and emissions of carbon dioxide equivalent are closely connected. Of all domestic vacuum cleaners, robot vacuum cleaners have the highest lifecycle impacts as they use a large amount of energy in the maintenance mode (maintenance mode is the power consumption when the vacuum cleaner is standing in the docking station fully charged) and contain a high number of printed circuit boards and the biggest battery. Most emissions during the device's lifetime, assumed to be 6 years, can be allocated to the use phase, 47 per cent, and material use, 44 per cent (Figure 3.3). Because of similar high energy use in maintenance mode, cordless vacuum cleaners also have a high environmental impact but a lower one than robots, as, due to using fewer materials, they are lighter.

It should be noted that if the lifetime of vacuum cleaners decreases, along with the increased energy efficiency and future electricity decarbonisation, the relative importance of the raw materials, production and waste management stages will increase. Therefore, even though further energy efficiency improvements will be necessary, optimising the use of raw materials, manufacturing, disposal and recycling of waste should also be considered to help achieve greater environmental improvements in the lifecycle of vacuum cleaners (Gallego-Schmidt et al., 2015). This will especially be the case for cordless and robot vacuum cleaners that have shorter lifetimes compared to mains-operated ones and are expected to account for 25 per cent of the market by 2023.

3.3.4 Measures

The growing demand for convenience by consumers and further development of AI and robotics will be an important driver in the vacuum cleaner industry. This will result in the increased popularity of cordless and robot devices that are more complex than traditional mains-operated vacuum cleaners. As these, however, have shorter expected lifetimes and higher impacts in the manufacturing phase, appropriate measures are needed.

3.3.4.1 Policy

Most vacuum cleaners that fall under the Ecodesign Regulations are already much more energy-efficient than required due to the market pull of energy labels– currently 50 per cent are in energy label class A (EC, 2019e). Therefore, setting stricter Ecodesign requirements would probably not have a significant impact on energy saving. The highest potential for energy saving is linked to cordless and robot vacuum cleaners but as these currently do not fall under the Ecodesign and Energy Labelling Regulations, there is no market push to increase their energy efficiency. Including both in the scope of the existing regulations might, however, create a pull towards more energy efficiency and reduced greenhouse gas emissions for these types of vacuum cleaner.

3.3.4.2 Repairability

Various studies have shown that the lifecycle cost for mains-operated vacuum cleaners are, in all cases, lower for repair (Bracquené, 2018; JRC, 2015). This requires both the availability of spare parts for up to eight years after the model has ceased being produced and limited labour costs, or at least that some of the repair can be done by the consumer. Most repair-prone products, such as hoses, must be replaceable without special tools (EC, 2019e). As vacuum cleaners become more advanced with printed circuit boards, cameras and sensors, these critical parts should also be easily replaceable.

Repairability of vacuum cleaners could be promoted through a proper design for repair and also the availability of information. More detailed information about the durability of vacuum cleaners would improve consumers' awareness and drive them towards more sustainable behaviour and choices, for instance regarding the proper maintenance of their vacuum cleaners or repairing, rather than replacing, their appliances (JRC, 2015).

3.4 Television

3.4.1 Overview

Televisions have been one of the key appliances in households since the mid-20th century, reforming communication in terms of news broadcasts and popularising entertainment. A long history from black and white cathode ray tube televisions (CRT) to, first, liquid crystal display (LCD) and plasma display panel (PDP) televisions, and on to new light-emitting-diode (LED) and organic light-emitting diode (OLED) sets has been enabled through innovation in TV-technology. Nowadays, televisions are much more than just broadcasting gadgets: smart televisions are connected to the internet, providing entertainment and services whenever needed. In 2017, around 95 per cent of households in the EU owned a television (EC, 2018b), making it one of the most popular domestic products. The viewing surface area of all televisions in the EU increased from 21 square kilometres in 1990 to 125 square kilometres in 2010, and is predicted to increase to 496 square kilometres(EC, 2019b).

The sale of television has grown steadily during the past decade. In 2018, in Europe roughly 70 million units were sold – about 15 per cent of global volume (Statista, 2019e,f) – relative 2012 when to 66 million units sold the increase has been around 6 per cent in six years. Revenues, however, have fallen from slightly above EUR 40 billion in 2012 to EUR 32 billion in 2018. The main reason for this is the decreasing unit price, which was roughly EUR 460 in 2018 as opposed to more than EUR 615 in 2012 (Statista, 2019e). Based on production and trade data, the EU has a notable share of Television, display and monitor production, resulting in just 10 per cent of devices sold being imported (Eurostat, 2019d).

In recent years, there has been rapid innovation in television technology. While roughly ten years ago flat panel LCD sets replaced the CRT televisions, today, different types of LED devices are becoming more popular. New television technologies have enabled an increase in screen size, brightness and higher resolution/definition – in 2018 the worldwide market share of screens of 55 inches (140 centimetres) or more was 27.5 per cent, while in 2017 it was 22.7 per cent; and the share of ultra high-definition (UHD) and 4K and above televisions has increased from 37.1 per cent in 2017 to 45.5 per cent in 2018 (Statista, 2019g). Many of the upgrades e.g. screen size or brightness was achieved without increasing the energy consumption of televisions in the past, but the latest technologies (UHD/4k) and features, such as smart television connected to the internet, do use more energy. A study by NRDC (2015) with 21–55 inch (53–

140 centimetres) televisions in 2014 and 2015 indicated that ultra-high-definition televisions consumed 30 per cent more energy than basic high definition (HD) models of the same size (NRDC, 2015).

The value chain for televisions includes many differen actors. The most central one is, of course, the manufacturer/brand, which has its own supply chain of component producers and raw material providers. Manufacturers/brands are in a key position when it comes to design-related action which may affect the lifetime or environmental impact of their products. Other relevant actors are the retailers, maintenance/repair and network/service providers; and as smart televisions become more popular, service providers will become more important. Finally, consumers play a significant role as they have the power to make the decisions about purchasing, repair and disposal. In the disposal phase, waste management companies and recyclers become important actors.

3.4.2 Product lifetime

Televisions have been a central item in households for decades suggesting that consumers were willing to invest in them even though they were expensive.

With the fall in their price and the increase in the standard of living, televisions are no longer considered luxury items and it is common now for households to have more than one. Buying of a new television set rather than repairing a broken one has become more customary (EC, 2018a), leading to shorter lifetimes. A study by Prakash (2016) showed that the average lifetime of a television is 10.2 years with the range from one year up to 40 years. However, as the 75 percentile was 14 years, it is likely that there are only few sets that are more than 20 years old. (Prakash et al., 2016) On the other hand a study by Wieser (2015) reported the average lifetime of a television is 7.3 years.

When looking at the lifetime changes through evolution in television technology, it can be observed from the designed lifetime perspective. The changes in designed lifetime are strongly linked to the technology used in the televisions. For CRT televisions, the designed lifetime was around 12,500 hours (King County, 2008), which, assuming a utilisation rate of 6 hours per day, corresponds roughly to 5.7 years. For LCD televisions, the designed lifetime is around 50,000–60,000 hours, which, assuming the same utilisation rate, allows a 22–27 year lifetime (Kalyani et al., 2017). For OLED televisions, a designed lifetime of as much as 100,000 hours has been mentioned, which, at the same usage rate, would provide a 45 year lifetime (Kalyani et al., 2017).

The primary causes for material obsolescence of television sets mainly relate to the display/screen unit, the power board, aluminium electrolytic capacitors and damage to delicate components resulting from transport (Prakash et al., 2016).

Material obsolescence does not, however, represent the primary problem for televisions according to an expert survey conducted in Germany (Hennies and Stamminger, 2016). The main cause of failure originated in software faults, referring to – incompatibility or functional obsolescence (Hennies and Stamminger, 2016). In incompatibility obsolescence, the rapid pace development in television technology in terms of resolution, new functionalities and a lack of standardisation play an important role. The development of new television formats in recent years has led older televisions lacking the necessary hardware chips. Furthermore, new functionalities, such as internet connection (smart televisions), generate significantly higher requirements for software (Prakash et al., 2016). Recently, it has been reported that streaming service providers have ended support for some older operating systems, making some smart televisions obsolete after just five years (Villas-Boas, 2019).

The most important reason for replacing an old television is attributed to psychological obsolescence. Research in Germany showed that more than 60 per cent of fully functional flat screen televisions TVs were replaced in 2012 because the owners wanted newer, better devices. Key factors in replacing a television were found to be the desire for a larger screen and better picture quality in combination with falling prices of devices (Prakash et al., 2016).

3.4.3 Environmental and climate impacts

In terms of environmental and climate impacts, the manufacture of an LCD television contributes around half of the greenhouse gas emissions of its entire lifecycle (Prakash et al., 2016).

The greenhouse gas emissions of an LCD television have been evaluated to be roughly 307 kilograms of carbon dioxide equivalent per year (kg CO_2eq/year), which is significantly higher than for other electrical equipment – desktop computers, for example, rank second with emissions of 156 kg CO_2eq/year (Manhart et al., 2016). The manufacture of printed circuit boards, in particular, contribute significantly to greenhouse gas emissions. Precious metals such as gold, palladium and silver are used in printed circuit boards. Especially the palladium production has a considerable effect in terms of photochemical oxidation due to the sulphur dioxide (SO_2) emissions to air (Hischier and Baudin, 2010). Other notable components are the backlight and, in case of LED televisions, the manufactur of LEDs themselves (Bhakar et al., 2015). From resource point of view, flat panel displays, independent of the technology, are the main consumers for indium, which is on the EU's critical raw materials list. Globally, 56 per cent of all the indium used is for flat panel displays in the form of indium tin oxide which can be deposited as a thin film on glass or plastic, and functioning as a transparent electrode. (EC, 2017a)

In their study, Prakash et al. (2016) showed that an LCD television with a ten-year lifetime consumes 28 per cent less energy demand and has a 25 per cent lower global warming potential than a television with a short lifetime (5.6 years) over a 10 year reference period. Over the given study period of 10 years, televisions with long lifetimes produce almost 600 kilograms less carbon dioxide than the short lifetime televisions.

Furthermore, the acidification potential, a key performance indicator in lifecycle analyses of acidic emissions or the acidification of air, soil or water, is 42 per cent higher for short lifetime televisions (Prakash et al., 2016).

When it comes to different television technologies, there is a limited amount of information in international literature. In one study, the energy consumption of different display technologies was analysed and compared (Park et al. 2011). While the shift in television technology from cold cathode fluorescent lamps (CCFL) to LED back lighted LCD displays has reduced the energy consumption by 20–30 per cent, the latest innovation in smart televisions is, once again, increasing energy consumption. The main reasons for this, even though the display technology may be the same, are advanced signal processing for network connectivity, larger/wider screens, increased daily usage, default white background screens, network standby modes and fast start options (Park et al., 2011).

As a result of network connectivity, for example, smart televisions consume 3–30 watts more in standby mode than conventional passive standby power mode which uses less than 1 watt (Park et al., 2011). In addition, new ultra-high definition (UHD) models, also known as 4K televisions, that provide superior picture quality with 8 million more pixels, have been reported to consume roughly 30 per cent more energy than traditional high-definition (HD) models. As an example, if all HD televisions above 36 inches (91.5 centimetres) in the United States of America were replaced with UHD models, an extra 4 million tonnes of carbon dioxide emissions would be produced per year (NRDC, 2015). The increase in energy consumption should be taken seriously since in 2016 the annual energy consumption of televisions made up more than 3 per cent the EU's electricity consumption (EU regulation, 2019/2021). From the environmental point of view, this trend leads to a situation in which it is desirable to use older, more energy efficient products for as long as possible (Bakker and Schuit, 2017). It should be noted, however, that older LCD televisions, using cold cathode fluorescent lamp (CCFL) technology, contain mercury which requires proper safe treatment in the end-of-life stage, but this is not the case with newer LED-based LCD televisions (Buchert et al., 2012).

3.4.4 Measures

As the trend in energy consumption of new television technologies and innovation may not move in the desired direction for the environment and the climate, both policy measures and new business models have a central opportunity that could affect the future landscape of television technologies and usage. While a sharing economy may not be the answer for extending televisions' lifetimes or lowering environmental pressures, ecodesign could hold the key for both.

3.4.4.1 Policy

In 2009, when the European Parliament and Council amended the already established framework for the setting of ecodesign requirements for energy-related products (Directive 2009/125/EC), televisions were one of the target products. Since then, changes in energy consumption moved in the right direction with the release of LED backlit televisions which consume less energy than previous LCD screens with cold cathode fluorescent lamp as a backlight or plasma display panels.

In the recast of the legislative framework related to ecodesign, the projected energy consumption of televisions, monitors and digital signage displays were be expected to rise to close to 100 terawatt hours per year by 2030. Through the revision, together with the accompanying energy labelling regulation, it is estimated that overall energy consumption will be reduced by nearly 40 per cent to 60 terawatt hours per year by 2030. In addition, specific requirements will be provided for standby, networked standby and off-mode electric power demand of the televisions (EU regulation, 2019/2021). When reflecting on this, together with the latest trends in energy consumption of new smart televisions described in previous sections, it is a welcome act.

Besides energy consumption, the recast of the EU's ecodesign requirements for energy-related products takes a stand on laying down suitable non-energy related requirements contributing to circular economy objectives including requirements to facilitate repair and spare-part availability (EU regulation, 2019/2021). This hopefully will have accelerating and positive effects on the new business models for repair at the end-of-life stage of the product.

3.4.4.2 Standardisation and lifetime requirements

Open, standardised testing methods to measure the service life of products and critical components would benefit various stakeholders over the lifecycle of a product. A number of standards and norms for components already exist to review safety and suitability for use in a device, but lifetime specific tests are lacking. (Prakash et al. 2016)

3.4.4.3 Software solutions and repairability

Software updates and hardware requirements have been one of the key causes of obsolescence in televisions. The creation of modular and innovative software solutions would, therefore, increase their lifetimes. In addition, software drivers and support over a sufficiently long period would have a positive impact on the extension of television lifetimes (Prakash et al., 2016).

From hardware point of view, easy access to and replaceability of components and parts, together with the availability of spare parts and including transparent information in anticipated costs, would assist repairability and would further increase the lifetime of equipment. One key aspect in the repair of older devices is to make it more competitive with new low-price products. (Prakash et al., 2016) Similarly to smartphones, repair businesses could be incentivised through reduced taxes (Bakker and Schuit, 2017).

3.4.4.4 Business and service models

Manufacturers' innovative service models, such as leasing, payback agreements and aftercare as a service, may help to achieve designed lifetimes in practice (Prakash et al., 2016). This would require a shift from owning a product to just using it, which may take time on the consumer market because of the heritage of the possession culture. In the business-to-business market, long-term service contracts and leasing are currently more common. (Bakker and Schuit, 2017)

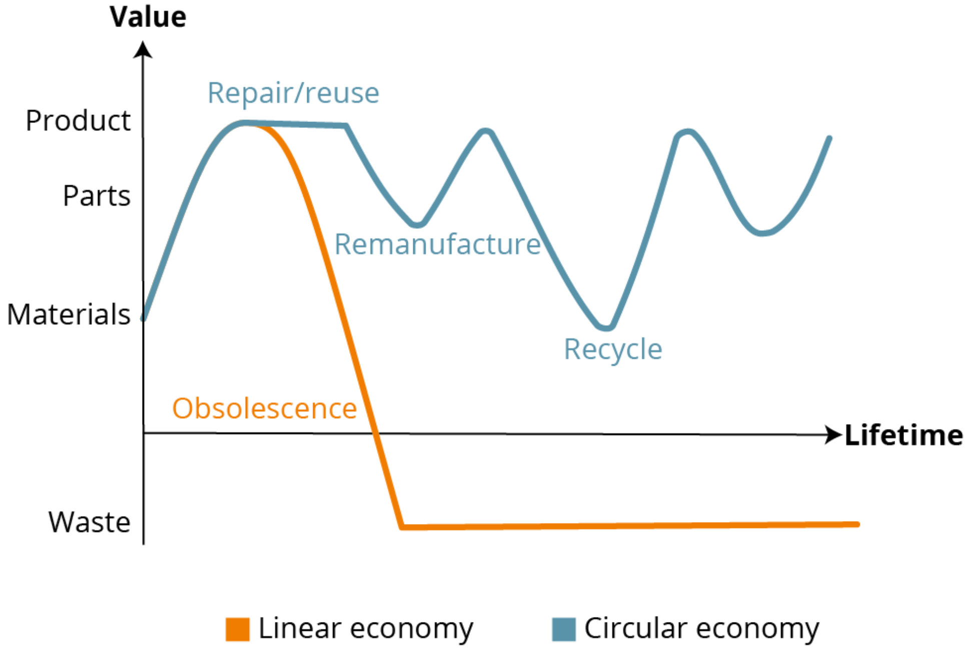
3.4.4.5 Consumer information

Since the decision to replace televisions is mainly driven by psychological obsolescence – the desire for new, larger and better-quality pictures, for example – consumer guidance and information are central to increasing product lifetimes. Improving consumer information on, for example, the ecological benefits of long-lasting products, and increasing information from manufacturers on such issues as the declaration of wear parts, are significant tools for influencing consumers to move towards products with extended lifetimes (Prakash et al., 2016). Moreover, guidance on how to best operate a product for optimal energy efficiency and extending its lifetime is key. For example, display modes, screen brightness and the level of room lighting can notably affect the energy consumption of a television (Bakker and Schuit, 2017).

4 Conclusions, circular business models and policy options

The increase in affluence during the last century, especially in the industrialised countries, have generated a linear economy and a consumer society. This growth came at the expense of resources, the environment and human health. Recently, moves towards a circular economy have shown the potential of decoupling growth from resource use, maintaining affluence and taking the environment, resources and health of people into account. A circular economy aims to maintain to value of products, components and materials throughout their entire lifecycles. The longer a product can retain its functionality, for example through repair or reuse, the higher value and environmental savings are obtained in the system (Figure 4.1). After a product reaches the end of its functional life, the reuse of components or parts (remanufacture) is preferred over (high value) recycling of it. Only if those circular economy strategies are not feasible, incineration comes into consideration as a last resort.

Figure 4.1. Schematic illustration comparing a linear design strategy with a circular design strategy with regards to value retention over the lifetime of a product

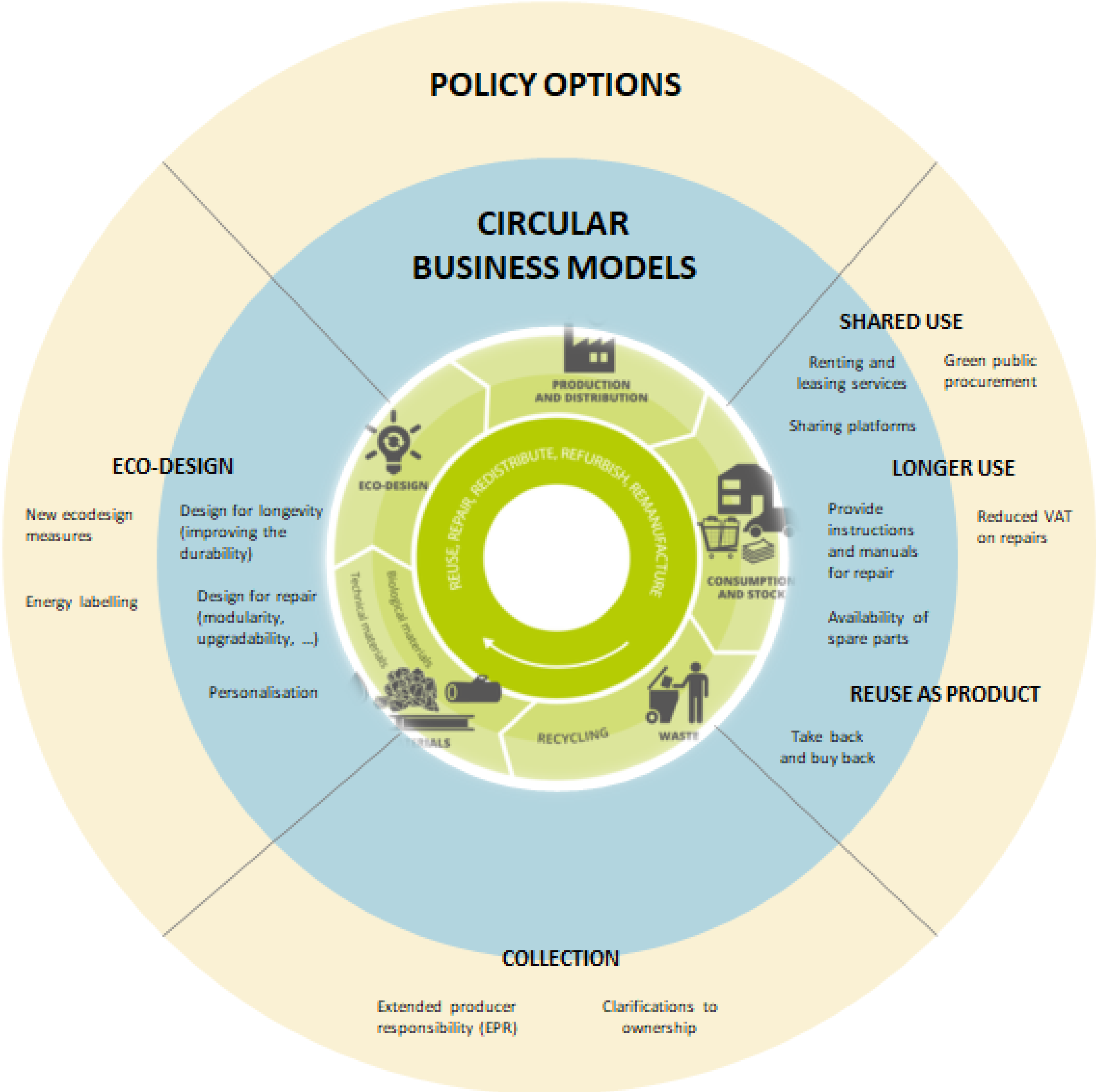


Source: ETC/WMGE

In achieving the aims of the circular economy, different business models such as product as a service, sharing of assets, extension of product lifetimes and recycling of previously unrecycled materials are a necessity on all levels. The electrical and electronic equipment sector is central to a transition to a circular economy as its products, resource intensive in terms of materials and energy, both in the production and usage phases, have significant environmental impacts throughout their lifecycles. In order to gain the potential of the circularity in electrical and electronics system, decreasing consumption and increasing lifetime of products are key actions

Various business models and policies that enable the transition to circularity (Figure 4.2) are examined in more detailed in the following sections.

Figure 4.2. Business models and policy options in relation to the lifecycles of electrical and electronic equipment system.



Source: ETC/WMGE

Business models

Business models enabling circularity and longevity of products occur at different stages of a product's lifecycle. The design phase is crucial since the choices and decisions affecting, for example, the product's durability and repairability are made at this stage. Generally, manufacturers can **improve durability** through the selection of materials and high-quality components whereas **repairability** can be facilitated, for example, through the way different parts can be disassembled and how they are attached to each other. Modularity not only has a positive effect on repairability but also on upgrading and the personalisation of products, which all may increase the product's useful lifetime. Beside modularity, **providing repair instructions and manuals, as well as spare parts for a sufficient period of time** are supportive in increasing a product's lifetime.

One mechanism to promote and accelerate the growth of the repair, refurbish and resale sector could be the **reduction of value added tax (VAT) on repairs**. This could address the economic misbalance of the cost of repair compared to the price of a new product being a barrier for repair for many electrical and electronical equipment (Bakker and Schuit, 2017; Watson et al., 2017). Another measure that might facilitate the repair and resale of second-hand devices is the **clarification of questions of ownership and treatment of waste electrical and electronic equipment**. Currently, ambiguity in the definition of discarded equipment may lead to a product becoming waste before it can be repaired. Once an object has been discarded as waste, it usually needs to undergo an procedure, which can range from something relatively minor to quite extensive processing, before it cease to be waste again. It could be beneficial for there to be a clear differences between reuse as a waste prevention measure on the one hand, and reuse following a material recovery processing on the other. (Watson et al., 2017)

The use phase of product may see rather big changes in the future as a culture of **owing products** shifts towards **using products**. Various new ownership models have and will be created. A common business model is the leasing through which customers leases the product at, for example, with a monthly cost for a given time period after which the product returns to the service provider. This is already rather common in the business-to-business market for example leased laptops at companies. A newer example is the product-as-service model throught which the customer purchases a service, such as light or cleanness of an apartment, from the service provider who owns the products which are used to provide the service. Even though the client/consumer may own a similar product which is used in the service, the intensity of its use decreases thereby increasing its lifetime. Another, more recent, business model is the **sharing economy** in which sharing platforms are provided to increase the usage intensity of products by sharing them with more users.

Enterprises may also opperate **take-back** or **buy-back** business models, in which old and possibly damaged products are handed in or bought back. These products can then be refurbished and resold, components removed for use in repairs/refurbishments or sent for recycling.

Policy options

Policy options are supporting and steering new business models and society action towards a more circular economy. The 2020 Circular Economy Action Plan of the European Commission addresses electronics and ICT as one of its key product and value chains The Commission promises to present a Circular Products Initiative mobilising existing and new instruments (EC, 2020). Directives to green public procurement and extended-producer-responsibility (EPR) schemes all target various product lifecycle stages to aid and create new business opportunities and lower environmental impacts.

In terms of Directives, the European Commission has adopted **new ecodesign measures** for ten products ([13]) which for the first time includes requirements for repairability and recyclability, which aim at contribute to circular economy objectives by improving lifespans, maintenance, reuse, upgrades, recyclability and waste handling (European Commission, 2019c). An example of the repair requirements for displays are (EU regulation 2019/2021):

- availability of spare parts, such as internal power supply, connectors to connect external equipment, capacitors, and batteries, for professional repairers for seven years after the last unit of the model is placed on the market;
- access to repair and maintenance information after a period of two years after the placing on the market of the first unit of a model or of an equivalent model;
- maximum delivery time.

Requirements for energy consumption, already been implemented in the Ecodesign Directive, have, for example, significantly increased the energy efficiency of vacuum cleaners.

Energy labelling has been an effective way of indicating the energy efficiency of products at the point of purchase, which has led to a decrease in the energy consumption of home appliances and greenhouse

[13] washing machines and washer-driers, dishwashers, electronic displays, household refrigerators, light sources, refrigerators with a direct sales function, external power supplies, electric motors, power transformers anf welding equipment

gas emissions across the EU. Since 1994 energy labels have guided consumers for a number of products. In 2021 five product groups ([14]) will undergo a rescaling under which A++ and A+++ labels will be gradually phased out and adjusted to reintroduce a simpler A to G scale (European Commission, 2019d). Products currently rated as A+++ could, for example, be regraded B, leaving A empty for new, more energy-efficient models. Interest has also been shown for lifespan labelling and the establishment of repairability criteria since both have been shown to positively affect purchase decision. In a study by European Economic and Social Committee it was noted that lifespan labels on products increased sales by 13.8 per cent (EESC, 2016). In 2018, a repairability scoring system for energy related products was developed for the Benelux region (Belgium, Netherlands and Luxembourg) (Bracquené E., 2018).

Public authorities in the EU have major purchasing power which can be used to contribute to sustainable consumption and production by selecting environmentally friendly goods, services and work. **Green public procurement (GPP)** is a voluntary instrument with clear and verifiable environmental criteria that has a key role in the EU's ambition to become more resource efficient, by stimulating a critical mass of demand for more sustainable goods and services. The European Commission has divided the criteria for monitors and computers into four categories: energy consumption, hazardous substance, product lifetime extension, and end-of-life management. The criteria on extending product lifetimes promote the use of minimum warranty and service agreements, guarantee the availability of spare parts, encourage design for repairability, including the easy access to and replaceable of parts; and ease of replacement of rechargeable batteries are important (EC, 2016).

Extended producer responsibility (EPR) ties a manufacturer to their product's post-consumer stage through extending their responsibility through the end-of-life stage. Extended producer responsibility is considered as a significant instrument in supporting the implementation of the EU's Waste Hierarchy which prioritises the prevention of waste generation followed by preparation for reuse, recycling, recovery and finally disposal (Directive 2008/98/EE). It is also mandatory within the context of the EU's Waste Electrical and Electronic Equipment, Batteries, and End-of=life vehicle Directives. In a study by Organisation for Economic Co-operation and Development (OECD, 2019b), it was observed that from the waste electrical and electronic equipment sector's point of view, online sales are seen as an increasing challenge for the extended producer responsibility system as sellers often do not have a physical legal entity in the country in which the consumer lives and are not registered with national or local EPR schemes. This results in the sellers avoiding producer and retailer/distributor obligations and costs, thus weakening the EPR system.

[14] fridges, dishwashers, washing machines, electronic displays including televisions and lamps

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