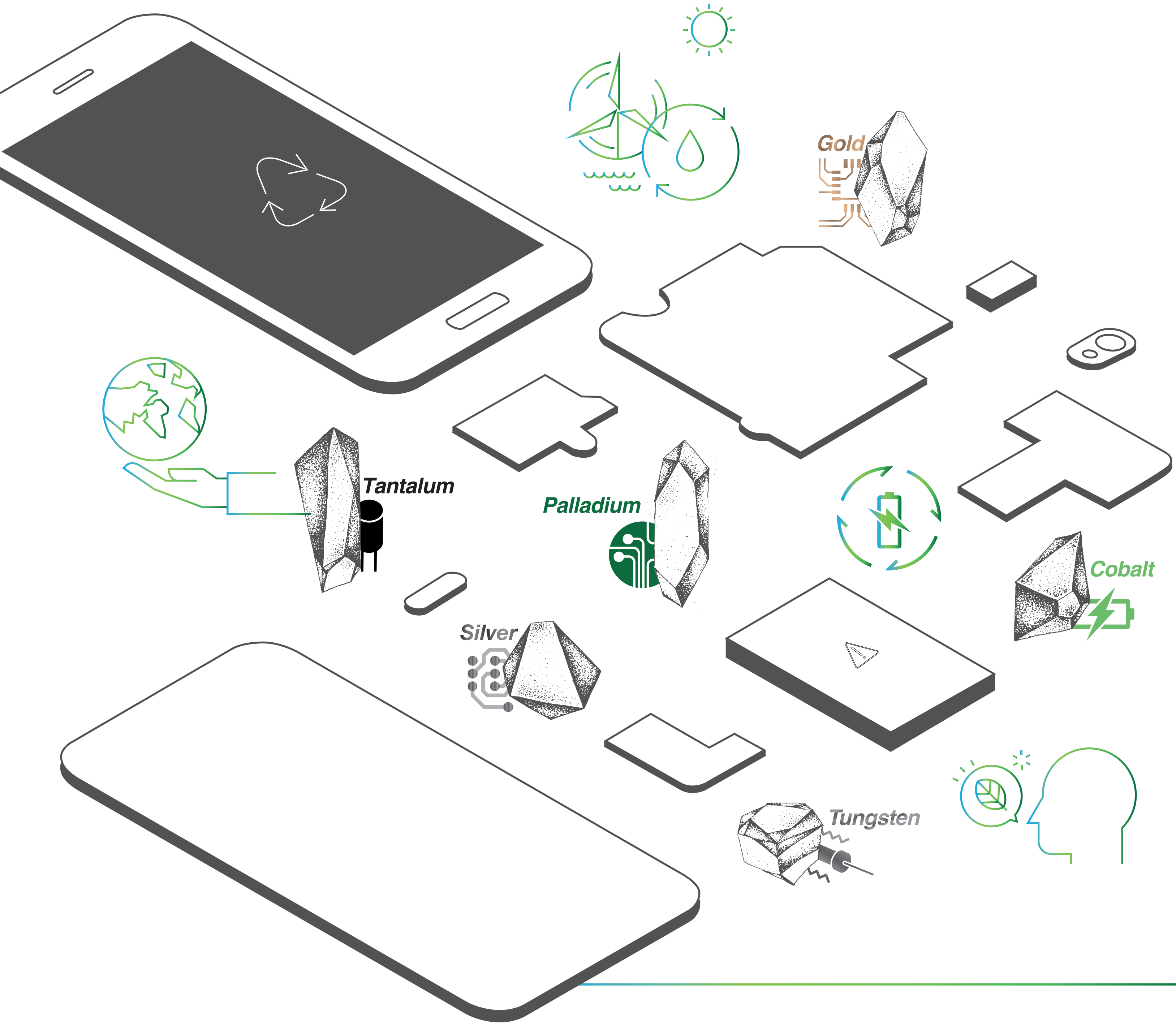
Resource Efficiency in the ICT Sector



GREENPEACE

Resource Efficiency in the ICT Sector
Final Report, November 2016

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List of Abbreviations

AMD	Acid Mine Drainage
ASM	Artisanal and Small-scale Mining
CFS	Conflict Free Smelter Programme
CFTI	Conflict-Free Tin Initiative
CPU	Central Processing Unit
CRT	Cathode ray tube
CVD	Chemical Vapour Deposition
DR Congo	Democratic Republic of the Congo
ECHA	European Chemical Agency
EEE	Electrical and Electronic Equipment
EICC	Electronic Industry Citizenship Coalition
EoL	End-of-Life
EPR	Extended Producer Responsibility
FC	Fluorinated Compounds
GeSI	Global e-Sustainability Initiative
HDD	Dard Disk Drive
ICT	Information and Communication Technology
ITRI	International Tin Research Institute
iTSCi	ITRI Tin Supply Chain Initiative
LCA	Life Cycle Assessment
NGO	Non-Government Organisation
NiMH	Nickel-metal hydride
PBB	Polybrominated biphenyls
PBDE	Polybrominated diphenyl ethers
PC	Personal Computer
PCB	Printed Circuit Board
PFC	Perfluorocompounds
PGM	Platinum Group Metals
RAM	Random Access Memory
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
REE	Rare Earth Elements
REO	Rare Earth Oxides
RoHS	Restriction of the use of certain Hazardous Substances
SfH	Solutions for Hope
SMD	Surface-mounted Device
SVHC	Substance of Very High Concern
3Ts	Tin, Tantalum, Tungsten
3TGs	Tin, Tantalum, Tungsten, Gold
USGS	United States Geological Survey
VOC	Volatile Organic Compounds
WEEE	Waste Electrical and Electronic Equipment

1. Background and introduction

Mobile electronic devices such as smartphones and tablet PCs have become an integral part of our daily lives and are used for virtually all aspects of modern communication and information sharing. While consumers and societies embrace the advantages of these modern information and communication technologies, NGO reports and other surveys reveal devastating environmental and social practices in the mining, manufacturing and disposal of mobile electronic devices. This includes UN-reports of warlords financing their existence with mining and trading of “high-tech minerals”; reports from devastating practices in cobalt-, tin-, gold-, palladium- and rare earth-mining; sub-standard working conditions in manufacturing and assembly and irregular recycling and disposal in third-world countries. In addition to these reports, it is well known that some production processes, such the microchip manufacture consume huge amounts of energy, water and chemicals. Moreover, electronic devices also contain substances which have adverse impacts on human and environmental health if not properly managed at the end of the product lifetime. In response, various countries have already introduced legislation aimed at reducing the negative environmental and social impacts of electronic devices. In parallel, the industry has also made considerable progress in terms of efficient use of materials, chemicals and the phase-out of substances of concern during the past years. However, many of the issues listed above have not been sufficiently addressed.

Against this background, Greenpeace assigned Oeko-Institut to give an overview of all the resource relevant steps of smartphones and tablets. Thus, the study’s aim is to present a comprehensive analysis of the resource related issues of smartphones and tablets, with relevance for the environment and human rights. In addition, the study aims to present existing approaches for mitigating the identified negative impacts. These approaches are described in the context of the ongoing scientific and policy debate and are meant to support further discussion and processes to find solutions.

While indirect impacts such as the energy and resource requirements of network infrastructure and datacentres are not part of this study, it focuses on all resource relevant processes within the life-cycle of smartphones and tablets. This means that this study solely addresses issues influencing resource consumption. Other environmental and social issues such as the use and emissions of hazardous substances within the product life-cycle and social conditions during mining, manufacturing, use and disposal are not addressed in detail in this study. Starting with an analysis of the global market situation (Chapter 2), this study includes the extraction of raw materials (Chapter 3), the manufacturing of components, devices and their relation to the total life-cycle impacts (Chapter 4), an analysis of product life-expectancy and the debate on obsolescence (Chapter 5) and the status and challenges of recycling (Chapter 6). In addition, this study entails an assessment of the legislative framework – in particular in the European context (Section 7.1) and voluntary improvement initiatives (Section 7.2). The most important findings from this analysis are compiled in Chapter 8, which is also the basis for Oeko-Institut’s recommendations.

In compiling this study, Oeko-Institut was able to draw from a broad variety of its previous research in virtually all of the fields addressed. While these research projects are referred to in the references section, Oeko-Institut also holds manifold experiences in related fields such as mining and mineral processing, hazardous substances, life-cycle assessment, eco-labelling and recycling. Although not entirely listed in the references section, these experiences also significantly contributed to the generation of this study.

2. Market trends

The sale and use of smartphones and tablets is increasing at rapid pace all over the world. While smartphones occupied only a very small niche market up to 2007, it is estimated that 2.16 billion people use a smartphone in 2016, which means that 46.4% of all mobile phone users and that 29% of the world population use a smartphone (eMarketer 2014a). Comparable developments can be observed for tablets: Tablet PCs were only sold and used in niche markets, a situation that changed with Apple's iPad in 2010. Today, it is estimated that 1.20 billion consumers, or 16% of the world population, use a tablet (eMarketer 2014b).

This rapid growth caused (and still causes) high sales numbers for both product groups: according to the market analyst company IDC, 1.433 billion smartphones and 206.8 million tablets were sold globally in 2015 (IDC 2015, 2016a, 2016b). Table 2-1 and Table 2-2 show the market shares of the major smartphone and tablet producers in 2015.

Table 2-1: Shipment volumes and market shares of major smartphone producers

Company	Shipments in 2015	Market share in 2015
Samsung	324.8 million	22.7%
Apple	231.5 million	16.2%
Huawei	106.6 million	7.4%
Lenovo	74.0 million	5.2%
Xiaomi	70.8 million	4.9%
Others	625.2 million	43.6%

Source: IDC (2016a)

Table 2-2: Shipment volumes and market shares of major tablet producers

Company	Shipments in 2015	Market share in 2015
Apple	49.6 million	24.0%
Samsung	33.4 million	16.2%
Lenovo	11.2 million	5.4%
ASUS	7.1 million	3.4%
Huawei	6.5 million	3.1%
Others	99.1 million	47.9%

Source: IDC (2016b)

3. Material requirements of ICT gadgets

Electronic devices contain a broad variety of materials, including many elemental substances that are widely regarded as critical and that are mined in small quantities only. Table 3-1 gives an overview of the material composition of smartphones and Table 3-2 on those of tablets. The data of both tables are based on various literature sources and our own selected measurements. The content data is indicative only and might vary significantly from model to model. It has to be stressed that the compilation of both tables lacks data on various elements. In particular there is no data for the content of beryllium and lithium, which are both commonly used in electronic devices. While beryllium is used for bonding wires, amongst other things, lithium is major material for the LiIon batteries that power virtually all mobile phones and tablets. The tables display bills of material on an elementary level, at least in relation to the various metals. As a consequence compounds such as PVC and flame retardants are not addressed as such. In addition to these shortcomings, the material composition might vary over time, which is not necessarily reflected in the data. Thus, the data and information in these tables should only be used for rough estimates.

Table 3-1: Indicative material composition of smartphones

Material		Main application	Content per smartphone	Content in all smartphones sold in 2014
Aluminium	Al	Case	22.18 g	28,851 t
Copper	Cu	Wires, alloys, electromagnetic shielding, printed circuit board, speakers, vibration alarm	15.12 g	19,665 t
Plastics	-	Case	9.53 g	12,397 t
Magnesium	Mg	Case	5.54 g	7,213 t
Cobalt	Co	Lithium-ion battery	5.38 g	7,002 t
Tin	Sn	Solder paste	1.21 g	1,573 t
Iron (steel)	Fe	Case	0.88 g	1,149 t
Tungsten	W	Vibration alarm	0.44 g	569 t
Silver	Ag	Solder paste, printed circuit board	0.31 g	397 t
Neodymium	Nd	Magnets of speakers	0.05 g	65 t
Gold	Au	Electronic components, printed circuit board	0.03 g	39 t
Tantalum	Ta	Capacitors	0.02 g	24 t
Palladium	Pd	Electronic components, printed circuit board	0.01 g	14 t
Praseodymium	Pr	Magnets of speakers	0.01 g	13 t
Indium	In	Display	0.01 g	7 t
Yttrium	Y	LED-backlights	0.0004 g	0.5 t
Gallium	Ga	LED-backlights	0.0004 g	0.5 t
Gadolinium	Gd	LED-backlights	0.0002 g	0.3 t
Europium	Eu	LED-backlights	0.0001 g	0.1 t
Cerium	Ce	LED-backlights	0.00003 g	0.03 t
Others	-	Glass, ceramics, semiconductors….	99.29 g	129,181 t
			160 g	**208,160 t**

Input data and sources:
- Average weight: 160 g (from own analysis of current models)
- Weight of battery: 39 g (from own analysis of current model)
- Average display size: 75.53 cm^2 (from own analysis of current models)
- Cu-concentration: 12.8% of device without battery (Hagelüken & Buchert 2008)
- Sn-concentration on: 1.0% of device without battery (Hagelüken & Buchert 2008)
- In-content: 700 mg/m^2 display (Buchert et al. 2012)
- Co-content of battery: 13.8% (Buchert et al. 2012)
- Weight of W-containing part of vibration alarm: 0.46 g (from own analysis of one current model)
- Ta-content of Ta-capacitors: 36.7% (Buchert et al. 2012)
- Magnet-composition: Fe = 68.0% ; Nd = 24.8%; Pr = 6.2% ; B = 1.0% (Buchert et al. 2012)
- Data on Au, Ag, Pd, Nd, Pr concentrations from Buchert et al. (2012)

Assumptions:
- Concentrations of Al, Mg, Fe and plastics equivalent to those given by Schischke et al. (2014) for 7-9 inch tablets
- Total weight of Ta-containing capacitors: 0.05 g
- The concentrations of Y, Ga, Gd, Eu, Ce correspond with those given by Buchert et al. (2012) for notebooks with LED backlights but decrease linear with decreasing display-size.
- W-concentration of W-containing part in vibration alarm: 95%

Table 3-2: Indicative material composition of tablets

Material		Main application	Content per tablet	Content in all tablets sold in 2014
Glass	-	Display	66.53 g	15,275 t
Aluminium	Al	Case	56.59 g	12,994 t
Copper	Cu	Wires, alloys, electromagnetic shielding, printed circuit board, speakers	40.79 g	9,366 t
Plastics	-	Case	26.49 g	6,081 t
Cobalt	Co	Lithium-ion battery	15.55 g	3,570 t
Magnesium	Mg	Case	13.57 g	3,116 t
Tin	Sn	Solder paste	3.19 g	732 t
Iron (steel)	Fe	Case	2.44 g	559 t
Neodymium	Nd	Magnets of speakers	0.60 g	137 t
Silver	Ag	Solder paste, printed circuit board	0.31 g	70 t
Tungsten	W	Vibration alarm	0.27 g	61 t
Praseodymium	Pr	Magnets of speakers	0.15 g	34 t
Tantalum	Ta	Capacitors	0.04 g	8.4 t
Gold	Au	Electronic components, printed circuit board	0.03 g	6.9 t
Indium	In	Display	0.02 g	4.9 t
Palladium	Pd	Electronic components, printed circuit board	0.01 g	2.5 t
Yttrium	Y	LED-backlights	0.002 g	0.4 t
Gallium	Ga	LED-backlights	0.002 g	0.4 t
Gadolinium	Gd	LED-backlights	0.001 g	0.2 t
Europium	Eu	LED-backlights	0.0003 g	0.07 t
Cerium	Ce	LED-backlights	0.0001 g	0.02 t
Others	-	Ceramics, semiconductors….	204.43 g	46,938 t
			431 g	**98,958 t**

Input data and sources:	Assumptions:
- Average weight: 432 g (from own analysis of current models) - Weight-% of battery: 24.3% of 7-9-inch tablets; 27.3% for 9-11-inch tablets (Schischke et al. 2014) - Weight-% of printed circuit board: 8.2% of 7-9-inch tablets; 5.6% of 9-11-inch tablets (Schischke et al. 2014) - Average display size: 307.6 cm2 (from own analysis of current models) - Glass content of display: 66.53 g (from own analysis of one current model) - Cu-concentration: 12.8% of device without battery (Hagelüken & Buchert 2008) - Sn-concentration on: 1.0% of device without battery (Hagelüken & Buchert 2008) - In-content: 700 mg/m^2 display (Buchert et al. 2012) - Co-content of battery: 13.8% (Buchert et al. 2012) - Weight of W-containing part of vibration alarm: 0.28 g (from own analysis of one current model) - Total weight of Ta-containing capacitors: 0.10 g (from own analysis of one current model) - Ta-content of Ta-capacitors: 36.7% (Buchert et al. 2012) - Total weight of NdFeB-magnets: 2.4 g (from own analysis of one current model) - Magnet-composition: Fe=68.0%; Nd=24.8%; Pr=6.2%; B=1.0% (Buchert et al. 2012) - Data on Au, Ag and Pd concentrations from Buchert et al. (2012)	- Concentrations of Al, Fe, Mg, glass and plastics equivalent to those given by Schischke et al. (2014) - Additional Fe is contained in speaker magnets (see above) - The contained amounts of Au, Ag and Pd are equivalent to those of smartphones - The concentrations of Y, Ga, Gd, Eu, Ce correspond with those given by Buchert et al. (2012) for notebooks with LED backlights but decrease linear with decreasing display-size. - W-concentration of W-containing part in vibration alarm: 95%

These material requirements are compared to the total primary (mine) production during the same time period (2014). As the global mining data does not yield a material specific production volume for rare earth elements, the rare earth elements contained in smartphones and tablets (Nd, Pr, Y, Gd, Eu, Ce) were summed-up to one figure for this exercise.

Table 3-3: Total material requirements of smartphones and tablets in relation to the world primary production of mineral commodities

Material		Content in all smartphones & tablets sold in 2014	World primary production in 2014	Global average recycled content (for all applications)	Percentage of smartphone & tablet demand of world primary production
Aluminium	Al	41,845 t	49,300,000 t	> 25-50%	0.085%
Copper	Cu	29,031 t	18,700,000 t	> 10-25%	0.16%
Cobalt	Co	10,572 t	112,000 t	> 25-50%	9.4%
Magnesium	Mg	10,329 t	907,000 t[1]	> 25-50%	1.1%
Tin	Sn	2,305 t	296,000 t	> 10-25%	0.78%
Iron (Steel)	Fe	1,708 t	1,190,000,000 t[2]	> 25-50%	0.00014%
Tungsten	W	630 t	82,400 t	> 25-50%	0.76%
Silver	Ag	467 t	26,100 t	> 25-50%	1.8%
Rare Earth Elements	REE	250 t	110,000 t[3]	< 1% & 1-10%[4]	0.25%
Gold	Au	46 t	2,860 t	> 25-50%	1.6%
Tantalum	Ta	32 t	1,200 t	< 10-25%	2.7%
Palladium	Pd	17 t	190 t	> 25-50%	8.9%
Indium	In	12 t	820 t	> 25-50%	1.4%
Gallium	Ga	0.9 t	440 t	> 10-25%	0.21%

[1] Data for magnesium metal.

[2] Data for pig iron.

[3] Data for rare earth oxides (REO).

[4] < 1% for Sm, Eu, Tb, Ho, Er, Tm, Yb, Lu; 1-10 % for La, Ce, Pr, Nd, Gd, Dy.

Input data and sources:
- Material content in smartphones and tablets: See Table 3-1 and Table 3-2
- World primary production: (U.S. Geological Survey 2015b)
- Global average recycled content: (UNEP 2011)
- To compare REE and REO volumes, the following assumptions were used 80% of REE-content = Nd, 20% of REE-content = Pr. Prevailing oxides for Nd and Pr: Nd_2O_3, Pr_6O_{11}

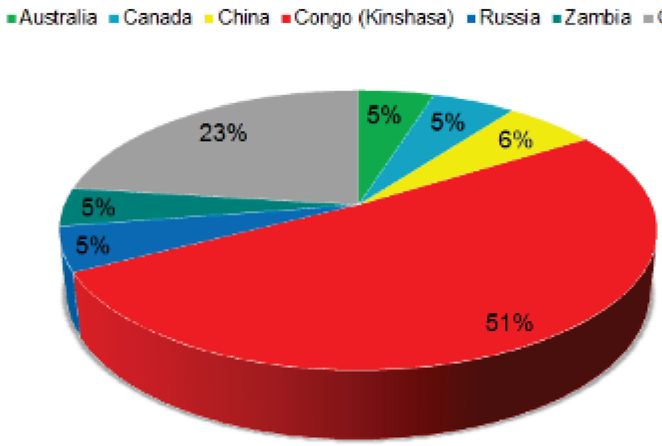
The analysis yields that smartphones and tablets are quite important applications for cobalt (~ 9.4% of world primary production) and palladium (~ 8.9% of world primary production). The global production of these two product groups is also a relevant factor in the global demand of tantalum, silver, gold, indium and magnesium (between 1% and 3% of world primary production). Nevertheless, the calculated values in Table 3-3 are based on various assumptions and should not be overstressed. They are only indicative figures and should be carefully reviewed with additional analytic efforts before being used for decision-making. Generally, such industry shares of the global material demand are important indications for the potential influence of a sector on upstream activities. Therefore, the following analysis will focus on cobalt, palladium, tantalum and silver. While other element (e.g. copper, aluminium) are relevant materials for these types of devices from the total material consumption, they have a relatively low shore of the global demand and are therefore not discussed in detail here.

3.1. Environmental impacts and risks

3.1.1. Cobalt

As illustrated in Figure 3-1, more than 50% of the world's primary cobalt supply is sourced from the Democratic Republic of the Congo (DR Congo).

Figure 3-1: Country shares of primary cobalt production in 2014



Source: U.S. Geological Survey (2015b)

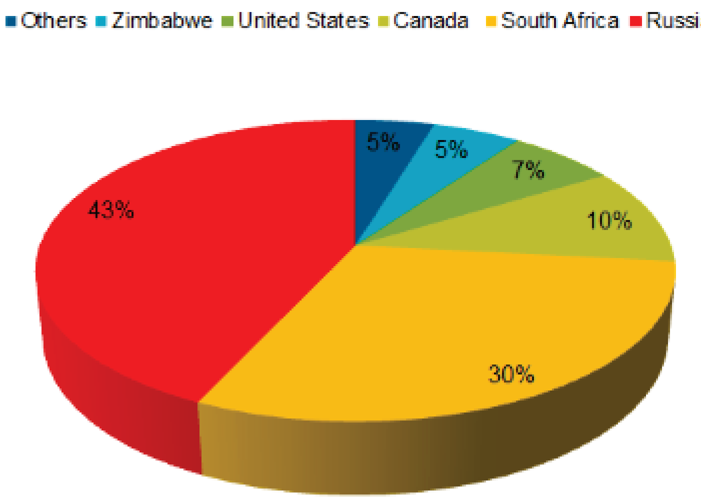
In the DR Congo, cobalt deposits are mainly concentrated in the so-called copper-belt in the south-eastern province of Katanga. This copper belt stretches east into Zambia. This region hosts the world's biggest cobalt reserves (U.S. Geological Survey 2015b). According to Pact (2010) and Tsurukawa et al. (2011), the cobalt mining in the DR Congo is associated with the following environmental issues:

- Due to a widely unregulated mining industry, extraction is done without regard to other land-uses. Thus, it is often associated with land degradation and loss of agricultural opportunities. Rehabilitation of mining areas is uncommon.
- Cobalt ores of the African copper belt often contain elevated concentrations of heavy metals and uranium. Due to these elevated uranium concentrations, some ores and tailings pose radiologic risks to persons being exposed to the material over longer time periods.
- Together, the combination of the first two issues lead to situations in which mining waste is not properly managed. Due to the geochemical composition of these mining wastes, emissions of heavy metals to water, soil and air are common.

3.1.2. Palladium

As indicated in Figure 3-2, 73% of the world's palladium production is mainly mined in two countries: Russia and South Africa. Generally, palladium is an element of the platinum group metals (PGM), which also encompass platinum, ruthenium, rhodium, osmium and iridium. In geological deposits, these elements mostly occur together. PGMs are mostly mined from nickel-ores, but also as by-products from copper- and chromium-ores.

Figure 3-2: Country shares of primary palladium production in 2014



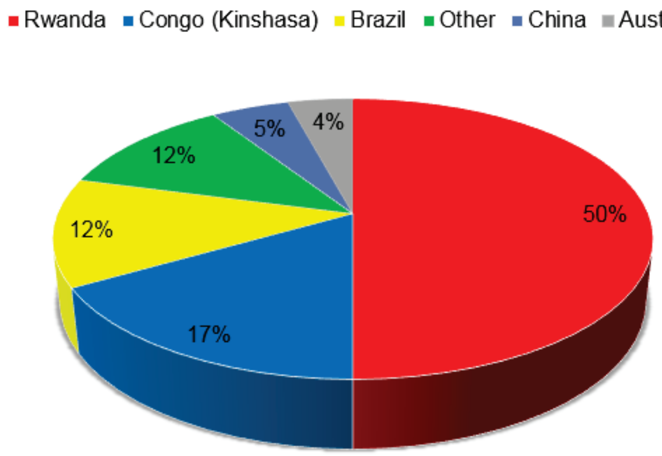
Source: U.S. Geological Survey 2015b

Production within Russia and South Africa is highly concentrated. In Russia, the majority of the production comes from Norilsk. Although the area is widely closed for external evaluations, it is ranked amongst the world's 10 worst polluted places by the US-American Blacksmith Institute and the Swiss Green Cross (Blacksmith Institute & Green Cross Switzerland 2013). According to this study, pollution is mostly caused by smelting operations with insufficient pollution control measures. The main problems are the release of heavy metals and sulphur dioxide. All platinum group metals are known for their high energy requirements in mining and processing. On average, the production of 1 kg of palladium requires a total primary energy input of more than 0.12 million MJ (Ecoinvent 2015).

3.1.3. Tantalum

As illustrated in Figure 3-3, 67% of the world's primary tantalum supply comes from Rwanda and the DR Congo. It is noteworthy that other potential tantalum producing countries (e.g. Australia) have higher production costs and therefore only become relevant at higher world market prices.

Figure 3-3: Country shares of primary tantalum production in 2014



Source: U.S. Geological Survey 2015b)

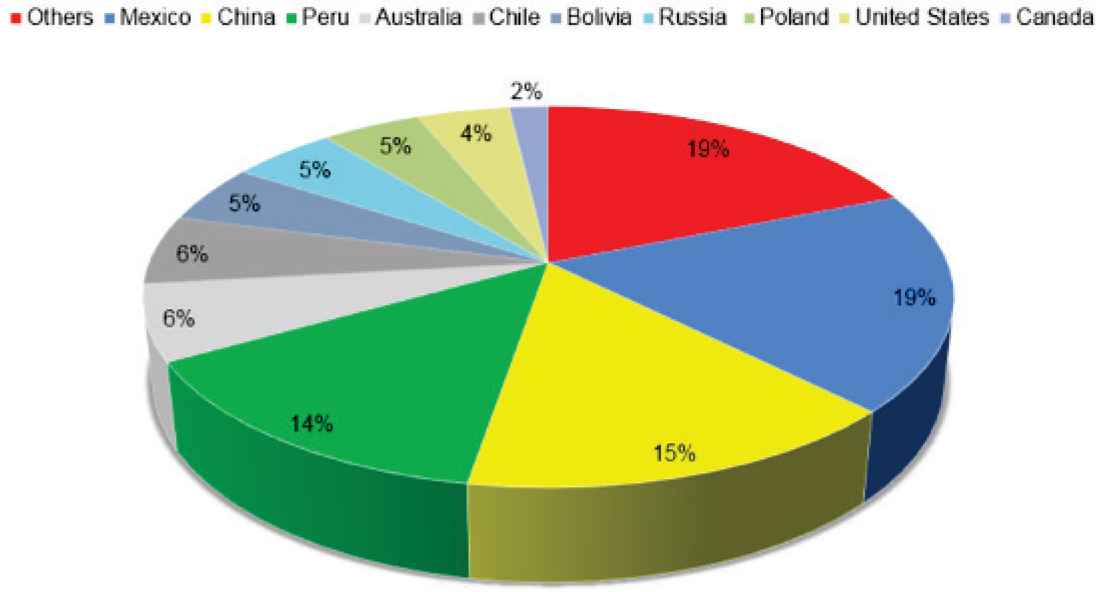
Tantalum mining in the two Central African countries is widely carried-out using artisanal methods. From an environmental perspective, such methods have the advantage of being quite energy extensive as many mining steps are conducted using manual force. In contrast, tantalum mining in Australia (which is currently not operating) has quite a high energy-input of around 24,000 l diesel and 155 kWh of electricity per tonne of Ta_2O_5 (Manhart et al. 2015). On the other hand, artisanal mining areas are mostly not subject to any rehabilitation. In addition, exploration and exploitation is often uncontrolled, which can have significant impacts on the local environment.

Tantalum ores are often associated with quite high concentrations of radioactive substances (uranium and thorium). Radiological data from tantalum ores in China show that the mined material usually exceeds the radiologic exemption level of the International Atomic Energy Agency (Dehoust et al. forthcoming; Hua 2011). For the same reason, a tantalum mining project in Ethiopia had to stop operation (Commodity Discovery Fund no date; U.S. Geological Survey 2015b).

3.1.4. Silver

As visualised in Figure 3-4, there is no clearly dominant production country for silver. In almost all cases, silver is mined as a by-product of other ores such as lead-zinc, copper and gold. From a global perspective lead-zinc ores are the most relevant type of silver-containing ores (U.S. Geological Survey 2015b). This combination with lead and zinc minerals also means that the environmental problems from lead-zinc mining and processing can also be partly attributed to silver.

Figure 3-4: Country shares of primary silver production in 2014



Source: U.S. Geological Survey (2015b)

Generally, mining and processing of lead-zinc ores is often subject to two major environmental problems:

- Lead is a heavy metal and despite being one of the target metals of mining and processing activities, lead emissions to water, soil and atmosphere are common. In addition, the ores are often associated with elevated levels of other heavy metals such as cadmium and arsenic. These heavy metals can cause problems in the management of mining waste (e.g. tailings) and also during the smelting operations.
- Lead-zinc deposits are sulfidic. Once the mined and grinded material is exposed to atmospheric weathering, a complex chain of biochemical processes can lead to a drop in aquatic pH-level. Subsequently this so-called acid mine drainage (AMD) can mobilise heavy metals contained in the mining waste material. Furthermore, the sulphur content of ores causes the formation of SO_x in roasting and smelting operations.

3.2. Social issues & human rights

3.2.1. Cobalt

Despite being mined in the Democratic Republic of the Congo, cobalt is not listed as a “conflict mineral” under the US-American Dodd-Frank Act or the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (see Section 7.1.4). The reason is that the area of the copper belt were cobalt is mined has not been affected by armed and violent conflicts after the end of the Second Congo war in 2002/2003.

Nevertheless, cobalt mining in the DR Congo has manifold adverse social impacts in the region, which are thoroughly described by Amnesty International (2016), Pact (2010) and Tsurukawa et al. (2011):

- A significant share of the Cobalt production is done using artisanal methods (artisanal and small scale mining – ASM). Although these labour-intensive mining methods provide income opportunities to about 120,000 – 150,000 individuals, the work is associated with significant and potentially fatal hazards such as flooding, insufficient mine ventilation and collapse of underground pits.
- In addition, artisanal miners are usually not equipped with any protective equipment and are therefore exposed to health hazards such as inhalation of dusts. Together with long working hours and the physically demanding nature of artisanal mining, adverse health effects are widespread.
- Child labour is common – in particular in the beneficiation of ores (crushing, washing and sorting) and collecting of ores from surface deposits and mining tailings. It is also reported that some children work in underground mines.
- Artisanal mining is partly carried-out in densely populated areas such as the city of Kolwezi. In these locations, mining has a severe impact on urban development.
- Although not interlinked with armed and violent conflicts, cobalt mining activities often cause tension with local populations. Common reasons for such tension are the negative impacts on other activities and land-uses such as agriculture and housing. In addition, tension exists between artisanal miners and operators of larger mining concessions.
- Artisanal miners are often subject to illegal taxation by government officials or unjustified fines and duties by mine guards.

3.2.2. Palladium

As indicated in Section 3.1.2, the Russian mining city of Norilsk – where a large portion of the world's palladium supply comes from – is ranked amongst the worst polluted places in the world. Thus, these environmental impacts also have a strong social dimension as they impact on the health of workers and local residents (Blacksmith Institute & Green Cross Switzerland 2013).

PGM mining in South Africa has been repeatedly subject to labour disputes. In 2014, at least 70,000 mining workers were on strike for several months demanding higher wages (U.S. Geological Survey 2015b). Social tension, labour disputes and unrest have been troubling characteristics of the South African PGM mining industry for several years. The situation peaked on 16th of August 2012 when police opened fire on wildcat strikers in the Marikana area. 34 workers were killed in the incident. The labour situation in South Africa's mining industry is characterised by fiercely competing labour unions, which makes it difficult to negotiate lasting agreements between management and workers.

3.2.3. Tantalum

Mining and trade of tantalum ores in the eastern part of the Democratic Republic of the Congo is known to be interwoven with the financing of various armed groups of the region[5]. This situation was identified as major factor prolonging the civil war and instability in the region (Manhart & Schleicher 2013). As a reaction, the UN Group of Experts on the Democratic Republic of the Congo, the OECD and the UN Security Council developed and endorsed the concept of human rights due diligence for tantalum using industries. With Section 1502 of the Dodd-Frank Act, the USA was the first country that made such due diligence requirements obligatory within its

5 In addition to tantalum ores, also tin ores, tungsten ores and gold are known to be conflict financing in the eastern DR Congo. Together these resources are commonly named 3TGs (Tin, Tantalum, Tungsten, Gold).

jurisdiction (see Section 7.1.6). Despite these measures, the human rights issues around tantalum mining in the eastern DR Congo are not fully resolved. Amongst others, a recent report from the UN Group of Experts on the Democratic Republic of the Congo documents that various armed groups still profit from mineral exploitation in the region and that non-certified ores are smuggled into neighbouring Rwanda (UN Group of Experts on the DR of the Congo 2015). Thus, it has to be assumed that at least some of the production volumes indicated in Figure 3-3 for Rwanda in fact originated from the DR Congo.

On the other hand, the labour intensive nature of small scale and artisanal mining (ASM) is a major source of income in the Central African region. For this reason, Rwanda encourages small scale mining industries for poverty reduction strategies. As indicated in Section 7.2.1, some local projects try to improve transparency and general working conditions in the artisanal mining of 3TGs without reducing job and income opportunities for the local population.

3.2.4. Silver

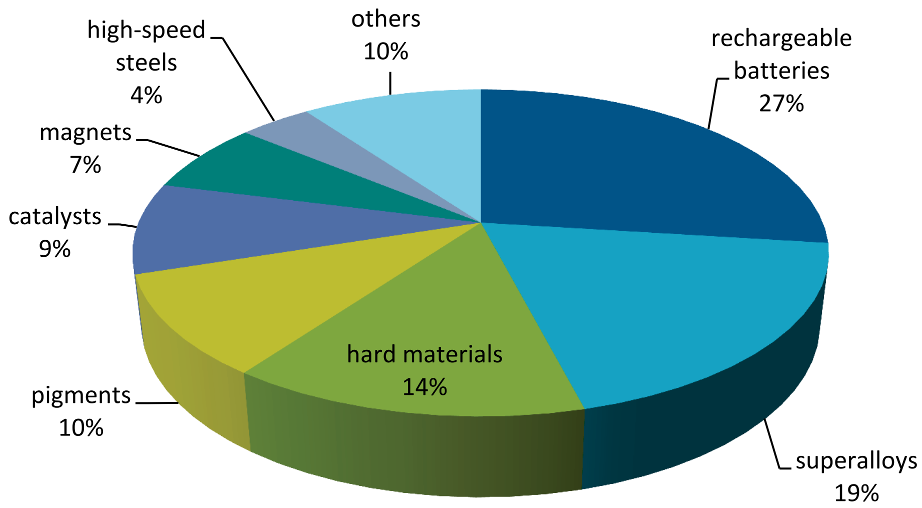
The social issues of silver production widely correlate with the environmental problems briefly described in Section 3.1.4. Local contamination of silver containing lead-zinc ore mining and processing can severely impact the health of workers and neighbouring communities. Amongst others one particular hot spot of primary lead-zinc production is Kabwe in Zambia, which is listed amongst the world's ten worst polluted places (Blacksmith Institute & Green Cross Switzerland 2013).

3.3. Material-uses in other sectors

3.3.1. Cobalt

As illustrated in Figure 3-5, with 27% of the world cobalt demand, rechargeable batteries are the most important application for this material.

Figure 3-5: Applications of cobalt

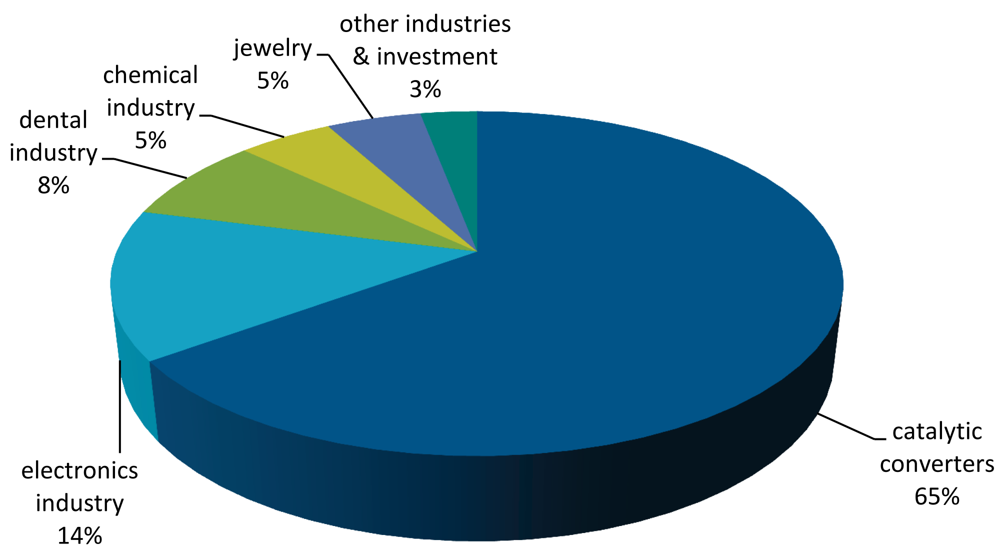


Source: British Geological Survey (2010)

3.3.2. Palladium

The most important application for palladium is catalytic converters. With 14% of the total world demand, applications in the electronics industry rank second.

Figure 3-6: Applications of palladium



Source: U.S. Geological Survey (2015a)

3.3.3. Tantalum

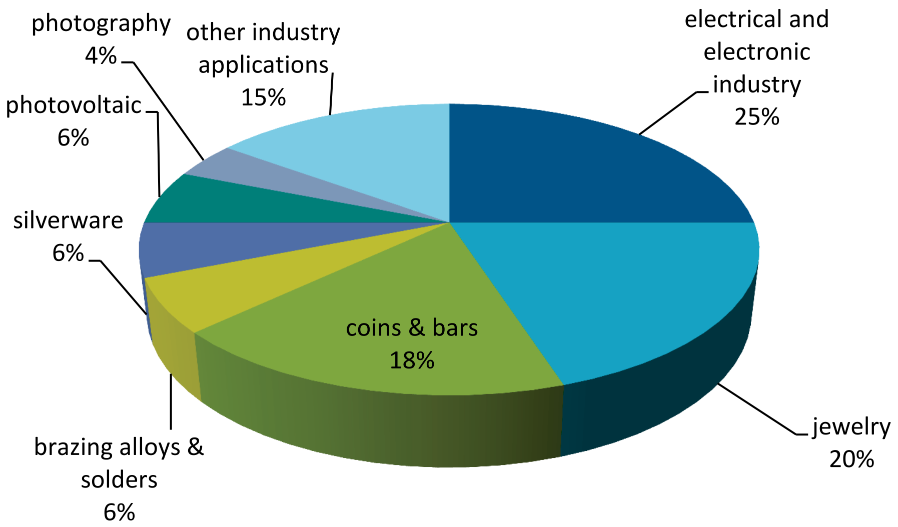
There are no global statistics on all tantalum end-uses available. A USGS report indicates that 50-60% of the world's tantalum production is used in the electronics industry, where the majority of tantalum is used for capacitors (40% of the total tantalum consumption in 2011). 20% of the tantalum is used in the metallurgical industry. The Ta-containing products of the metallurgical industry (e.g. superalloys) are used in a broad variety of industries such as aerospace, gas-turbines and others (U.S. Geological Survey 2013).

3.3.4. Silver

The electrical and electronic industry uses one fourth of the global silver production, which is the biggest single industry application for this metal. As silver is commonly used in lead-free solders[6], it is contained in a wide variety of devices.

6 As described in Section 7.1.1, lead is banned from the use in electrical and electronic equipment in various jurisdictions. Thus, lead-free solders are commonly used in the EEE industry globally.

Figure 3-7: Applications of silver



Source: The Silver Institute (2015)

4. Life-cycle global warming potential of ICT gadgets

ICT products lead to multiple environmental impacts over the course of their life-cycle. Some of the impacts include global warming potential, terrestrial acidification potential, freshwater eutrophication potential, water depletion potential, cumulative energy demand, fossil resource consumption and many more. In this report, the focus lies on the global warming potential, largely due to the availability of a large number of studies dealing with the greenhouse gas emissions of smartphones and tablets.

4.1. From cradle to grave: Greenhouse gas emissions of tablets & smartphones

Figure 4-1 displays the results of a number of Life-Cycle Assessment (LCA) studies carried out to calculate the life-cycle based greenhouse gas emissions of smartphones. The studies show a wide range of estimated total greenhouse gas emissions (16 kg CO_2e to 110 kg CO_2e) for different smartphone models. However, a commonality among the studies shown in Figure 4-1 is the relative share of the different life-cycle phases in the total greenhouse gas emissions of smartphones. Figure 4-2 shows that the production phase accounts for 33% to 85% of the total greenhouse gas emissions of smartphones. The use-phase, which generally includes the greenhouse gas emissions as a result of electricity consumption at the premises of end-consumers (e.g. for charging the smartphones), was found to contribute about 10% to 49% of the total greenhouse gas emissions. The distribution phase was responsible for 3% to 17% of the emissions, while the contribution of the end-of-life phase (EoL) was seen to be negligible.

Life-Cycle Assessment (LCA) studies on electronic devices, including tablet PCs and smartphones, have repeatedly highlighted the fact that the **production stage** has a major impact on total greenhouse gas emissions of an electronic device. The share of greenhouse gas emissions of the production stage is largely attributed to the resource extraction and processing, component (part) manufacturing and assembly processes as well as device tests. In general, recent studies (e.g. Andrae & Andersen (2010); Gensch & Blepp (2014); Prakash et al. (2011)) have shown that the environmental impact of electronic products, especially of microelectronic components, was systematically underestimated in many studies in the past. Section 4.2 sheds some light on the energy-intensive processes required to manufacture microelectronic components. In this regard, it seems that some studies on smartphone models (e.g. iPhone 3GS, iPhone 3G and Fairphone 1) presented in Figure 4-1 have by far underestimated the environmental burden of the manufacturing phase of smartphones. On the other hand, models Fairphone 1, Nokia Lumia 820 and Sony Ericsson W390 may have underestimated the total greenhouse gas emissions of a smartphone altogether as their estimated greenhouse gas emission values lie at a comparatively much lower level than other models.

Similar to smartphones, several LCA studies on tablet PCs also highlight the importance of the production phase for overall greenhouse gas emissions. The analysis of various models of tablets (Figure 4-4) confirms that the highest share of greenhouse gas emissions lies in the production phase (79% to 85%). The use-phase accounts for 11%-16% of total greenhouse gas emissions. Other studies, such as Moberg et al. (2010), Dell (2011) and Teehan & Kandlikar (2013) also point towards a similar trend.

It is noteworthy that **the results of the LCA studies presented in Figure 4-1 are not comparable with each other**! The differences in the estimated greenhouse gas emissions of smartphones in various studies may not be attributable to any specific design-related aspect or major differences in the way these gadgets are produced, but are more likely primarily the result of differences in the methodological considerations in carrying out LCA. Methodological considerations, which significantly influence results of LCA studies, include definition of system boundaries of products, cut-off criteria, choice of datasets (e.g. primary and secondary data) and databases, representativeness of the technology as well as geographical scope and allocation rules. For example, when using secondary data, important differences in the overall results can result from different data sets used for upstream processes (e.g. data for precious metals and high-purity materials). The use of these data sets is not always transparent in the published results.

LCAs are, hence, rather a framework methodology applicable as a decision support instrument in the context of the following decision situations (ILCD 2010):

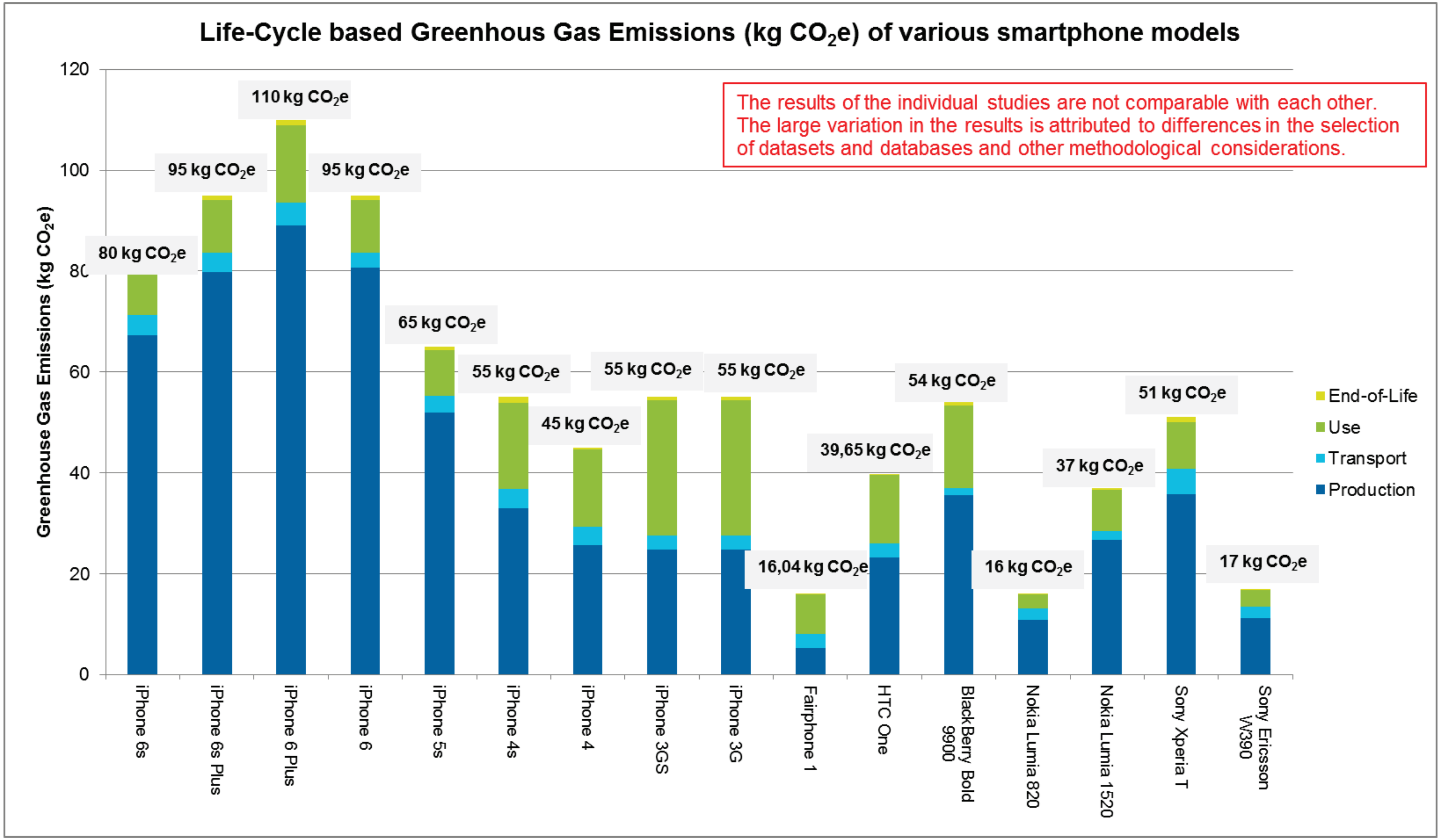
- Meso/macro-level decision support: strategic planning;
- Micro-level decision support: design and planning of products, facilities, and processes;
- Accounting: monitoring the environmental performance of companies or sectors

LCAs should, in consequence, generally not be used for direct product comparisons. It is, nonetheless, possible to increase comparability of different LCA studies by carefully aligning methodological choices. However, this can typically only be achieved if such a comparison is done within one study and sufficient information is available on all product systems studied. (comparative LCA). According to ISO 14040/14044, the requirements regarding reporting as well as critical review are much stronger for comparative studies.

For the future, up-to-date and critically-reviewed public data sets for important processes (e.g. raw material acquisition, transport, electricity) would help to improve the overall comparability of LCA studies and results, provided that major methodological choices are published together with results of LCA studies. To this end, the European Commission is currently implementing an initiative on Product Environmental Footprinting (PEF), which aims to improve comparability of LCA studies. However, it is yet unclear if this objective can eventually be achieved (see Section 7.1.6).

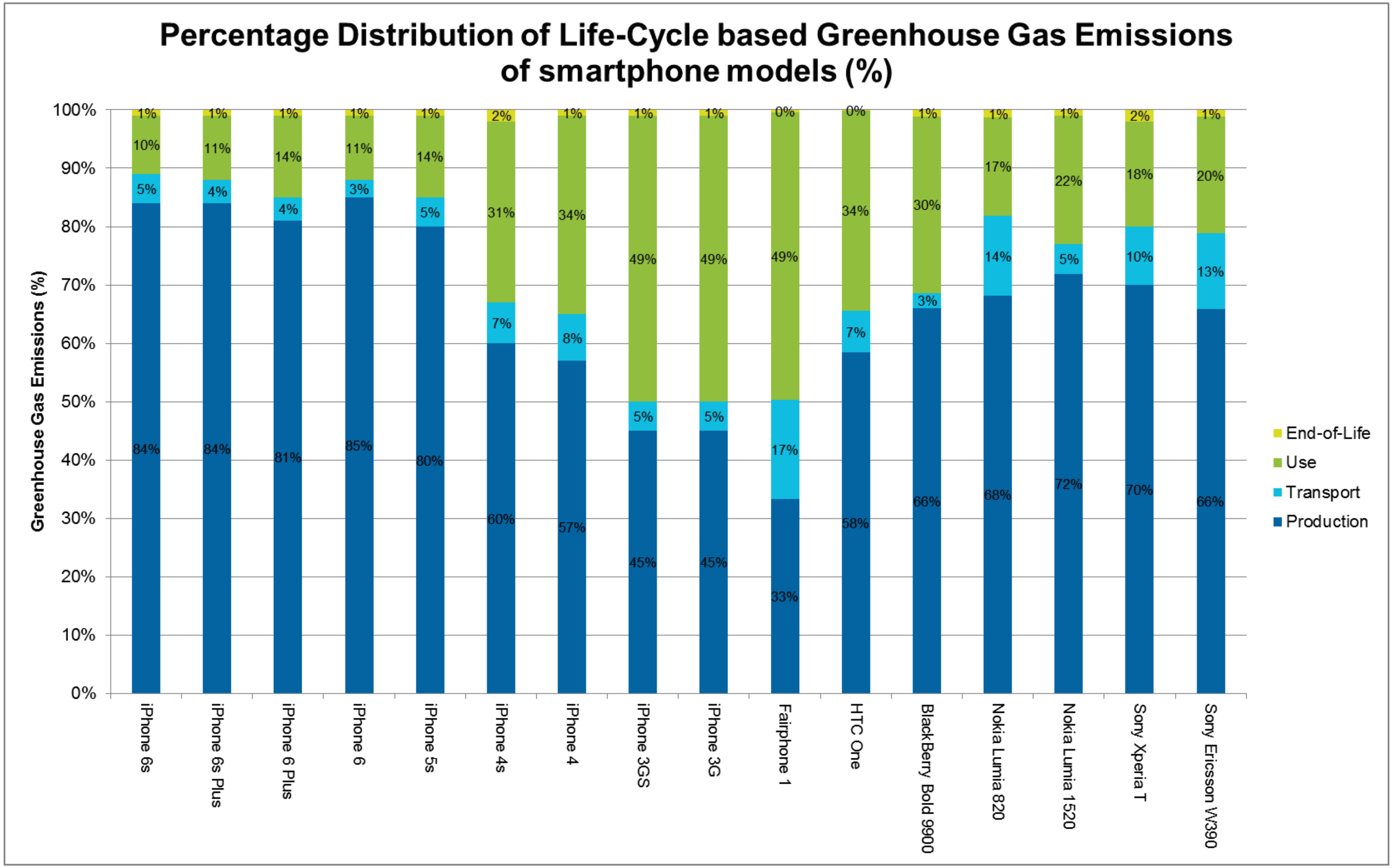
Finally, it is important to note that the implementation of LCA does not automatically improve the environmental performance of a company and their products. It serves as a knowledge support tool that can enhance environmental intelligence and trigger actions for improvement. In this respect, the life-cycle perspective helps avoid shifting environmental problems from one stage in the product life cycle related value chain to another one. It can also contribute to analyzing and evaluating trade-offs between the environmental implications of different design alternatives (Möller et al. 2015).

Figure 4-1: Life-cycle-based greenhouse gas emissions (kg CO_2e) of various smartphone models



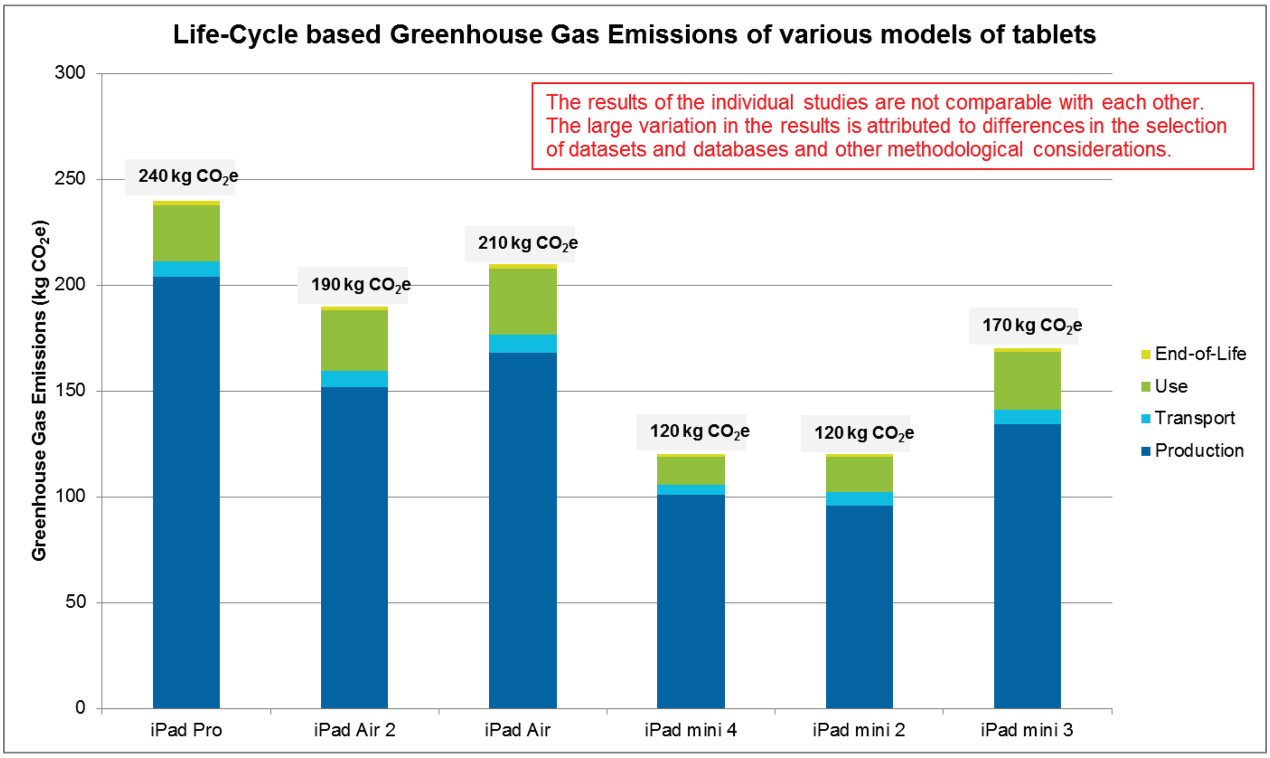
Sources: Apple (2016); Fairphone (2015); HTC Corporation (2013); BlackBerry Ltd. (2016); Güvendik (2014); production phase includes resource extraction and processing

Figure 4-2: Percentage distribution of life-cycle-based greenhouse gas emissions of smartphone models (%)



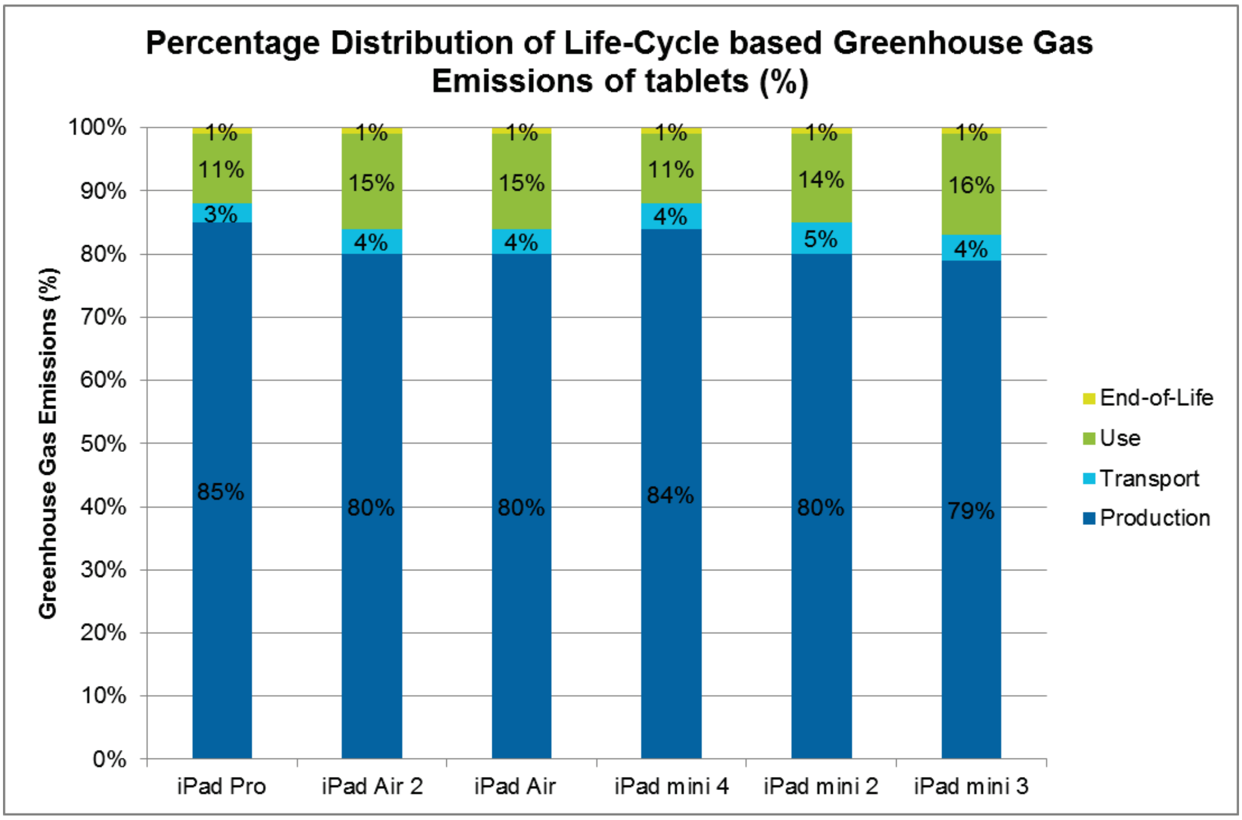
Sources: Apple (2016); Fairphone (2015); HTC Corporation (2013); BlackBerry Ltd. (2016); Güvendik (2014) ; production phase includes resource extraction and processing

Figure 4-3: Life-cycle-based greenhouse gas emissions of tablet models (CO_2e)



Source: Apple (2016); production phase includes resource extraction and processing

Figure 4-4: Percentage distribution of life-cycle-based greenhouse gas emissions of tablet models (%)



Source: Apple (2016); production phase includes resource extraction and processing

The key factors for the lower contribution of the use-phase to overall greenhouse emissions of smartphones and tablets are extremely low power consumption during use and relatively short life expectancy. Smartphones and tablets usually have 2-3 years of average service life. In terms of power consumption, the following table compares the average annual energy consumption of various ICT devices in the use-phase:

Table 4-1: Average annual consumption of ICT devices in the use-phase (2011)

ICT Device	Annual Energy Consumption (kWh/a)
Smartphone (Standard user)	3
Smartphone (Heavy user)	6
Tablet PCs	7
Landline/ DECT Telephones	31
Notebooks	58
Home gateways	68
Desktop-PCs	128
Game consoles	197
Televisions (LCD)	219

Source: Prakash et al. (2014)

However, it has to be critically noted that network usage as well as data centre services (e.g. online storage, video streaming) are not included in the estimation of the use-phase greenhouse gas emissions. Prakash et al. (2014) show that the largest growth of electricity consumption in the ICT sector is expected for data centres and telecommunication networks. The electricity consumption of data centres in EU-27 is forecast to increase by almost 35% from 52 TWh in 2011 to 70 TWh in 2020, while the electricity consumption of the telecommunication networks is forecasted to increase exorbitantly by 150% from 20 TWh in 2011 to 50 TWh in 2020. The biggest growth is expected for mobile networks due to the immense growth of mobile data traffic, by a factor 30, caused by the increasingly intensive use of mobile internet services. This is enabled by more capable mobile networks (LTE technology) as well as an increasing number of mobile devices with significant computing power (smartphones, tablets). The high expected growth in electricity consumption by data centres is a result of an increase in the data traffic resulting in about fixed data traffic of about 22 EB[7] per month and about 970 PB[8] per month for mobile data traffic in 2016. Such trend is based on increased internet and cloud services usage, especially videos. In any case, the collective share of data centres and telecommunication networks in the total ICT related electricity consumption in EU-27 is expected to increase from 33% in 2011 to about 46% in 2020. In other words, data centres and telecommunication networks will contribute about 3.8% in the total electricity consumption in EU-27 in 2020, compared to 2.6% in 2011 (Prakash et al. 2014).

4.2. The big chunks – the most energy-intensive production processes

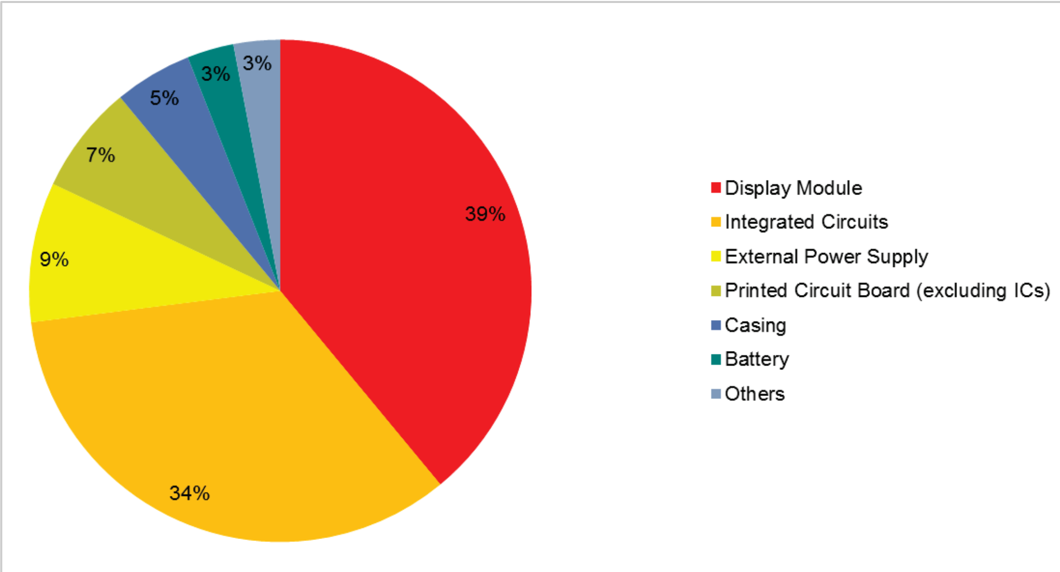
A closer look at the production stage of tablets and smartphones reveals that only a handful of components cause up to 80% of total greenhouse gas emissions from manufacturing. Mainly, printed circuit boards (PCBs), displays and integrated circuits are responsible for the largest share of greenhouse gas emissions in the production stage (see Figure 4-5 and Figure 4-6). Figure 4-5 shows that PCBs and integrated circuits contribute 41% and display modules 39% of the greenhouse gas emissions of tablet production. In Figure 4-6, it can be seen that PCBs and integrated circuits account for almost 36% (including assembly activities) and displays about 32% of the total greenhouse gas emissions of producing a smartphone. A recent study on the carbon footprint of

[7] Exabyte (EB) = 10^{18} Bytes

[8] Petabyte (PB) = 10^{15} Bytes

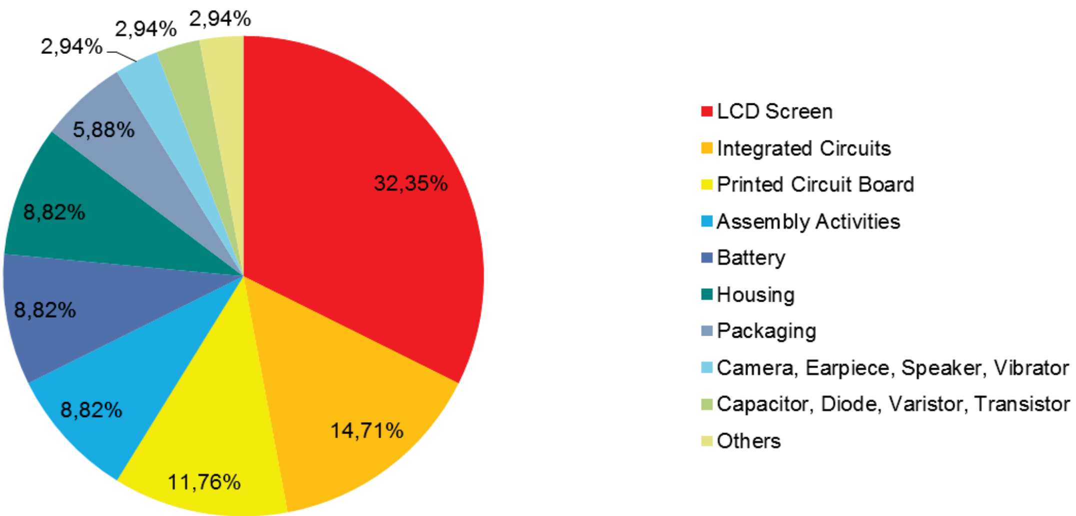
notebooks, which is based on updated datasets for the memory (RAM), CPU, display module, printed circuit board, hard-disk drive and battery, estimates the greenhouse gas emissions of manufacturing the RAM bars to be about 40% of the total greenhouse gas emissions of notebook production (Prakash et al. 2016b). The same study calculates the share of the motherboard to be about 37% and that of display to be about 6% (Figure 4-7).

Figure 4-5: Share of components in the greenhouse gas emissions (kg CO_2e) of the production of a tablet



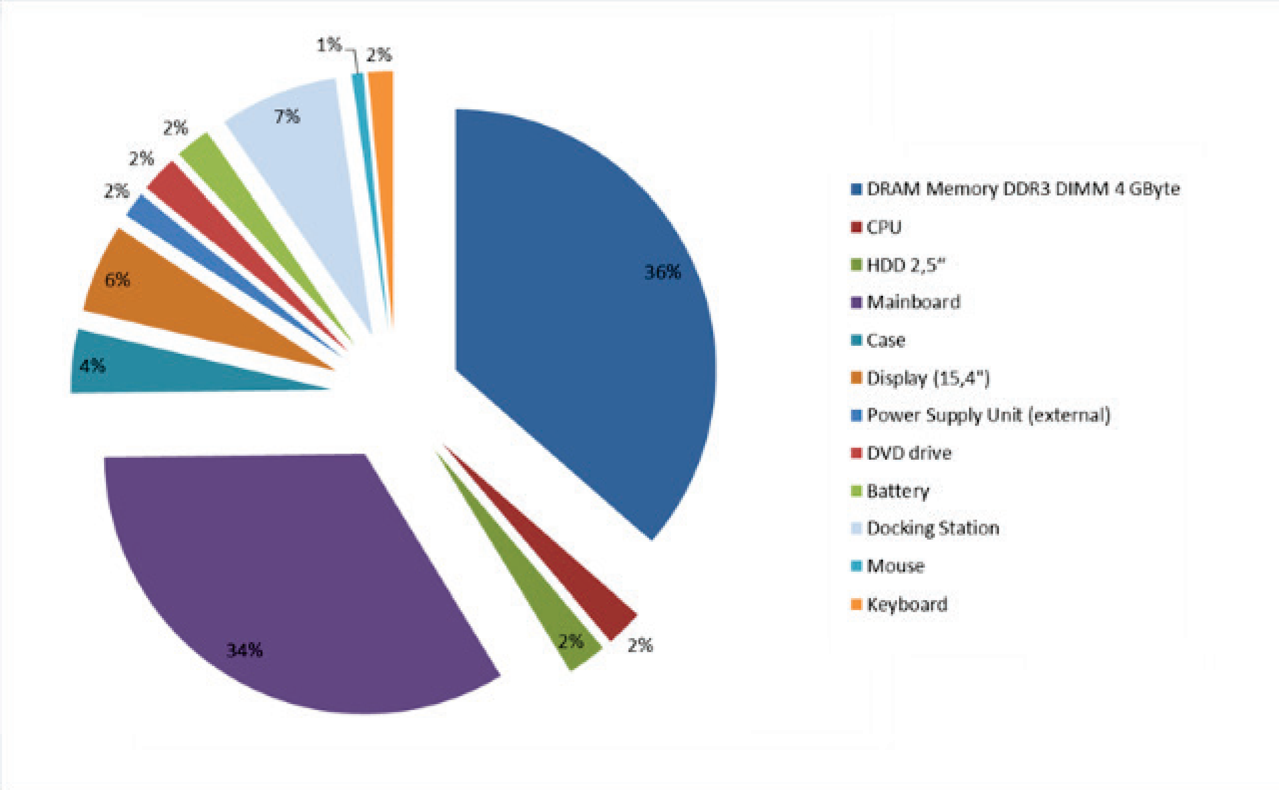
Source: based on Teehan & Kandlikar (2013)

Figure 4-6: Share of components in the greenhouse gas emissions (kg CO_2e) of the production of a smartphone



Source: based on Fairphone (2015)

Figure 4-7: Share of components in the greenhouse gas emissions (kg CO_2e) of the production of a notebook



Source: based on Prakash et al. (2016b)

Energy consumption in manufacturing as well as emissions of fluorinated compounds (FC), such as SF_6 and NF_3 (which are potent greenhouse gases[9]), are expected to play a significant role in the overall impact of displays. Prakash et al. (2011) showed that in fabs without FC emissions treatment, the greenhouse gas emissions of display production increasing substantially by 22%. According to Dell (2011), the impact of the display strongly correlates with its size – i.e., a smaller display has a reduced impact, while a larger one generates increased greenhouse gas emissions. If a smartphone display of 3" is used instead of 5", the total carbon footprint would be reduced by 7.5% and increasing the display size to 7" would increase the total carbon footprint by almost 19%.

The high impact of integrated circuits is largely attributed to their fabrication from high-grade silicon using an array of ultrapure chemicals in workrooms that must meet “cleanroom” standards. More than a hundred chips are placed simultaneously on a silicon wafer disk through a series of processes in the fabrication line. In general, the high-purity chemicals and ultraclean production conditions (cleanroom technology) that are required contribute to the environmental impact of these components, as larger amounts of materials and energy are required for their production / operation processes. An additional aspect of interest for environmental impacts concerns the application of perfluorocompound (PFC) emissions treatment which is not practiced in all fabrication facilities Prakash et al. (2011). The most prominent contributor to energy consumption and greenhouse gas emissions is the production of the RAM bars. Each RAM bar is populated with several integrated circuits and gold connectors (pins). With increasing internal memory in tablets

9 According to the Intergovernmental Panel on Climate Change, SF_6 has a global warming potential of 22,800 times and NF_3 of 17,200 times that of CO_2 when compared over a 100 year period.

and smartphones, a higher number of RAM bars and corresponding integrated circuits and gold connectors are used. This leads to an increase in greenhouse gas emissions, especially due to the energy-intensive manufacturing of the silicon wafer for the die. Furthermore, substrate manufacturing for the printed circuit board, including the assembly processes for populating the board with electronic components, represents another energy-intensive process. Other energy-intensive processes include manufacturing of standard active components, such as transistors and diodes, as well as of CPU and graphic cards, i.e. all components that contain a die, and hence are associated with the burden of wafer manufacturing.

Möller et al. (2015) summarizes the key drivers of energy consumption and climate change in the manufacturing of electronic devices as follows:

(1) **Clean room requirements**: The purpose of a cleanroom is to ensure a controlled low level of pollutants, such as dust, airborne microbes, aerosol particles and chemical vapours (Rumsey Engineers Inc. 2010). Cleanrooms constitute the most important energy consuming system within a typical semiconductor production site, causing almost as much electricity consumption as the complete manufacturing equipment. Cleanroom facilities encompass heating, ventilation and air conditioning (HVAC) systems, these processes accounting for 36–67% of the total facility energy (Tschudi & Xu 2001). Besides their traditionally importance for the production of integrated circuits, cleanrooms become more and more important in the production process of advanced printed circuit boards with ultrafine structures as well as of electrical components and accessories.

(2) **Use of compressed air**: Compressed air technology is used to clean electronic components and machinery as well as to power manufacturing equipment (e.g. assembly tools and air driven machinery), to hold, position, and assemble electronic components (e.g. LCD panels, printed circuit boards, memory chips, etc.). The production and supply of compressed air is considered to be the least efficient and most expensive of all energy carriers, making it the most polluting form of energy in the manufacturing process of electronic devices. For example, compressed air needs approx. ten times as much energy to produce the final energy provided during use, accounting for 10% of the total electricity consumption of production sites of electrical and electronic equipment. While demand for compressed air is rather stagnant, cooling systems are becoming increasingly important in the electronics sector.

(3) **Cooling technology**: Cooling systems are becoming increasingly important in the electronics sector. The most common application is the removal of process heat that accumulates in the production processes, but also in the production halls. In particular, the continuing trend towards increasingly fine structures, both in the production of integrated circuits and of printed circuit boards, increasingly requires the use of cooling technology. Together with compressed air, it represents the most excessive and thus polluting form of energy in the manufacturing process of electronic devices.

(4) **Soldering processes**: Soldering is most relevant for the production of printed circuit boards in order to connect the electronic components to the circuits on the board. Within the context of miniaturisation of electronic devices and as a result of an ever increasing number of surface mounted devices (SMD), reflow soldering is by far the most relevant soldering technology. Reflow soldering equipment is responsible for 70% of energy demand within the SMD production process (Bell et al. 2013).

(5) **Use of PFCs**: PFCs are important not only from the perspective of facility's energy consumption, but they are the most relevant contributor to a semiconductor fab's global greenhouse gas emissions because of the high global warming potential of PFC gases. The most relevant

PFCs that are used in the EEE sector encompass Hexafluoroethane (C2F6), Octofluoropropane (C3F8), Tetrafluoromethane (CF4), Octofluorocyclobutane (c-C4F8) (Möller et al. 2015). In terms of processes, these gases are required in particular for plasma etching and cleaning Chemical Vapour Deposition (CVD) reactors. The reduction and abatement of emissions of PFC is an important commitment of the semiconductor industry. CVD chamber cleans represent the largest source of PFC emissions (C_2F_6, CF_4) that reportedly constitute 80% of all semiconductor emissions (US-EPA 2006).

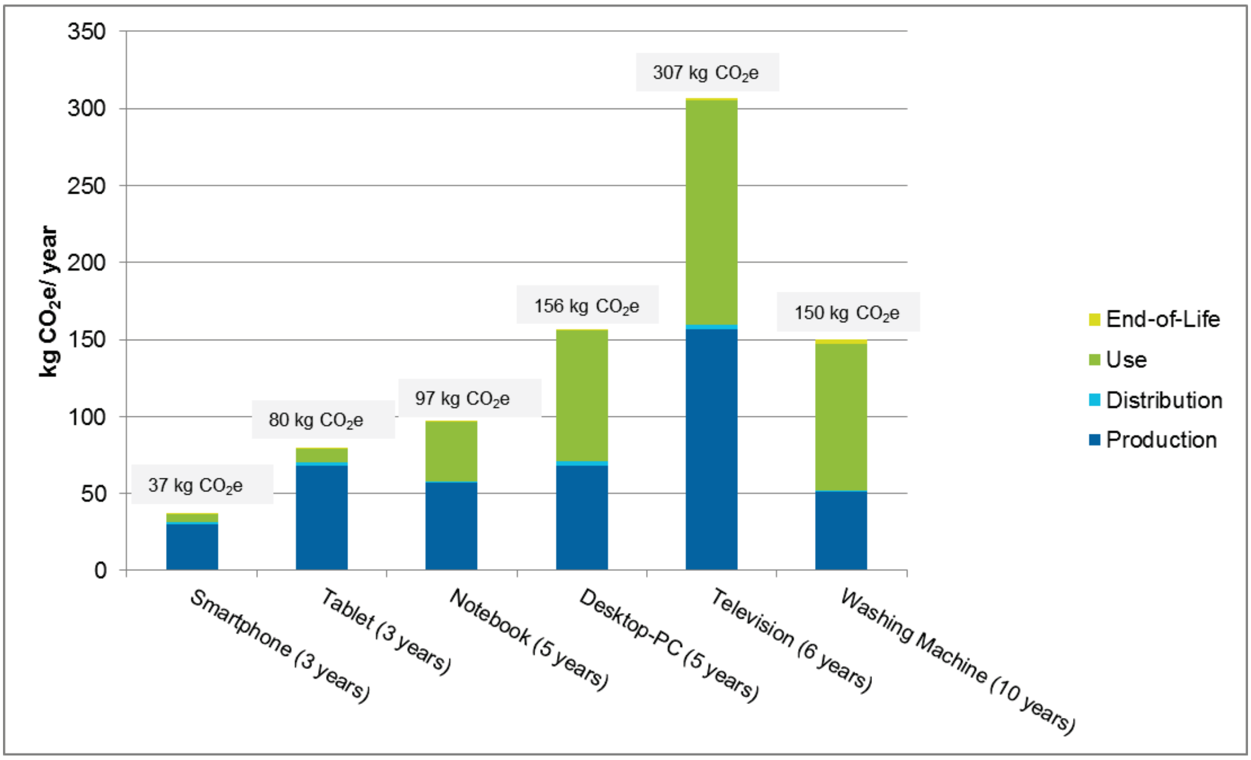
(6) **Use of VOC-based solvents**: Solvents based on Volatile Organic Compounds (VOC) are commonly used in the manufacturing of electronic components for processes such as cleaning or degreasing, stripping processes, for thinning coatings, and dissolving raw materials. Since the vast majority of organic solvents are derived from crude oil, a direct relation between the use of solvents and energy demand / resource depletion as well as associated greenhouse gas emissions is evident (ESRG 2010). For example, within the semiconductor industry, the VOC-based solvents considered to be of major importance are Amine-based hydroxylamine (HDA), Cyclopentanone, Dimethylformamide (DMF), Isopropanol, N-methyl-2-pyrrolidone (NMP) and Propylene glycol monomethyl ether acetate (PGMEA) (Möller et al. 2015).

Section 7.2.2 provides examples of best environmental management practices with regard to improving these particularly energy intensive manufacturing processes.

4.3. Smartphones and tablets – How do their impacts relate to those of other products?

A comparison of smartphones and tablets with other everyday products shows that smartphones and tablets, at least at the level of individual products, have an extremely modest environmental burden (Figure 4-8). It is the sheer number of total sales volume (refer to Chapter 2) which triggers the high environmental impact of producing these gadgets (refer to Section 4.1). In the following Figure 4-8, the annual greenhouse gas emissions of various ICT products, calculated proportionately according to the expected life-span (in brackets in Figure 4-8), are displayed.

Figure 4-8: Comparison of annual greenhouse gas emissions (kg CO_2e / year) of various products



Source: Values for smartphones (Figure 4-1, Model 3) and tablets (Figure 4-3, Model 1); notebooks and desktop-PCs on the basis of Prakash et al. (2016b); televisions and washing machines on the basis of Prakash et al. (2016a)

The total greenhouse gas emissions of a smartphone over an expected life-span of 3 years are comparable to watching 1,378 hours of television (assuming a power consumption of 120 W in On-Mode (Prakash et al. 2014). For an average TV-user, that would equate to watching 4 hours TV every day for about 11.5 months.

It is also comparable to about 254 washing cycles with a washing machine in Germany. Assuming 220 washing cycles per year with a washing machine (EU Commission 2010) and an energy consumption of 0.65 kWh per washing cycle (Gensch & Blepp 2014), this would equate to about 14 months of using a washing machine.

Lastly, the carbon footprint of smartphones is comparable to driving about 537 km in a car, assuming an average CO_2 emission of 205 g/km. This distance is equivalent to driving from Berlin to Frankfurt in about 5.5 hours.

5. Obsolescence: Life-time matters

Previous sections showed that the highest environmental impact of ICT products is attributed to the production phase. Hence, longer life-spans and usage times can significantly lower this environmental burden. The debate on how long devices last or how long they are used before being replaced by consumers is very much dominated by the technical term ‘obsolescence’. It generally refers to the natural or artificial ageing process of products (Prakash et al. 2016a; 2016b). This means that products lose their suitability to satisfy a certain need. The term is used with regards to (1) ageing or abrasion, and (2) early ageing or abrasion, while the latter can only be determined in relation to an expected life-time. However, expectations about lifetimes are subject to dynamic social processes that include very heterogeneous positions and perspectives of societal actors. A classification of types of obsolescence as well as typical causes for obsolescence for ICT products is provided in Section 5.2.

5.1. Trends in life span and usage times of tablets and smartphones

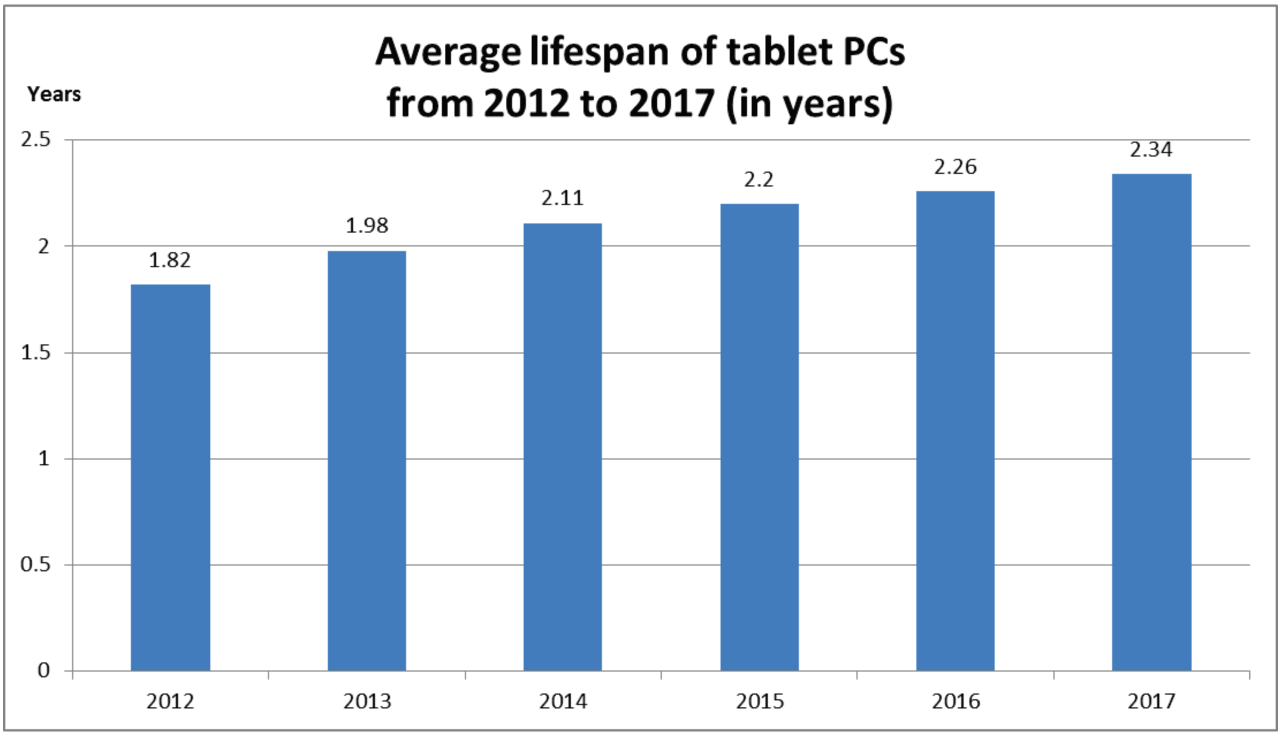
When comparing life times of products, it is important to differentiate between various definitions of the relevant time periods as defined in Prakash et al. (2016a).

- ‘Life-time’ refers to the average period between the first marketing of a product to its final failure.
- ‘Usage time’ (also service life) describes the time period a product is used by the user. Depending on the definition, this can also include a second or third use resulting from passing on to other users or resale. If this is not considered, the term ‘first usage time’ or ‘first service life’ is used.
- ‘Residence time’ includes the period between the sales of the product to the transfer into the waste stream. This means that if a broken device is kept in a user’s household after failure but not transferred to the waste stream yet, it is still in the residence time.

According to Huisman et al. (2012), the residence time of IT products declined by 10% between 2000 and 2010. Newer investigations show a more differentiated picture with regards to communication and information technology (ICT) products. In Prakash et al. (2016a), the example of notebooks shows that the average first service life of notebooks which were replaced due to a defect rose from 4.8 to 6.5 years between 2004 and 2006 and decreased again to 5.3 years in 2007. In the years 2010-2012, the average first service life of defect notebooks was between 5.4 and 5.7 years. Hence, a clear trend that notebooks break sooner over the time could not be confirmed from the data. But, it is noteworthy that replacement due to a defect accounted for over 25% of all replacements in 2012/2013 (see also Section 5.2 on material obsolescence). Those notebooks which were replaced because they were faulty and unreliable were aged 4.8 years on average in 2004. In the period up to 2012, the average first service life of these devices increased to 6.0 years in 2011 and 6.2 years in 2012. This trend indicates a decreasing susceptibility of the notebook computers to failures between 2004 and 2012. The average first useful service life of the functioning notebooks that were replaced because of the desire for a better device was approx. 6 years between 2004 and 2012 (see also psychological obsolescence).

Regarding tablet PCs, current data shows an inverse trend. As illustrated in Figure 5-1, the average life span of tablet PCs increased from an average of 1.82 years in 2012 to 2.26 in 2016.

Figure 5-1: Life span of tablet PCs is increasing

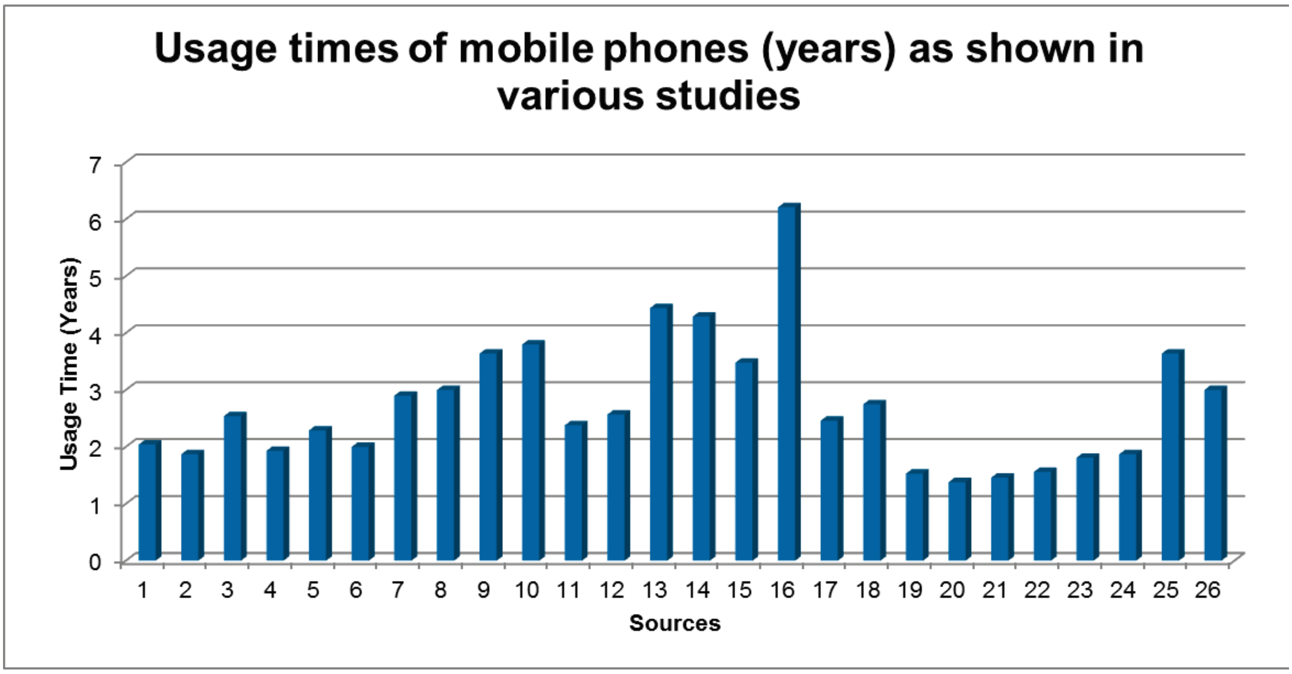


Source: Own illustration; data according to statista.com

With regards to mobile phones, consumer research from Japan has shown that the first useful service-life of mobile phones decreased from 2.54 years in 1995 to 2.29 years in 2007 (Murakami et al. 2010). Another consumer research from the Netherlands demonstrated that the median life-time of mobile phones declined from 4.8 years in 2000 to 4.6 years in 2005 (Bakker et al. 2014).

Wieser & Tröger (2015) did a comprehensive literature research on data for the usage times of mobile phones in various countries, such as the UK, Germany, Japan, USA, Finland and France (Figure 4-2). Usage times were seen to range between 1.38 years to 6.21 years. The average of usage time shown in Figure 4-2 lies at 2.72 years.

Figure 5-2: Usage times of mobile phones (years)



Source: based on literature research done by Wieser & Tröger (2015)

At the same time, Wieser & Tröger (2015) also collected consumer data (online survey and selected interviews) on the usage time of mobile phones in Austria. The average usage time of mobile phones/ smartphones was found to be 2.7 years.

In another study in the Netherlands, Huisman et al. (2012) calculated the percentage of products that were placed on the market in 2005 in the Netherlands, discarded by private households in the following years. For mobile phones, it was seen that almost 25% of mobile phones were discarded within the first two years. This figure, however, refers to the residential time of mobile phones in the households and is not to be confused with the usage time.

Finally, a survey by the German consumer magazine Stiftung Warentest in 2013 (test 2013) showed that 42% of respondents replace their mobile/smartphone within 2 years.

It is noteworthy that usage patterns of mobile and smartphones have changed significantly within a decade. User responses according to a recent survey by Prakash et al. (2014) show that apart from using the device for telecommunication (97%) and text messaging (89%), new functions such as photography and filming (88%), internet connection (82%), listening to music (59%) and navigation (52%) have expanded the usage pattern. Hence, it is important to consider the utility of the ICT products as well as new user patterns when looking at absolute life-spans and usage times (Prakash et al. 2016a; Prakash et al. 2016b).

5.2. Causes for obsolescence

As the causes for obsolescence are very diverse, the following typology is used in the current scientific debate (Bertling et al. 2014; Prakash et al. 2016a; 2016b):

5.2.1. Material obsolescence

'Material obsolescence' refers to an insufficient performance of materials and components. Product aging becomes obvious by (too fast) degradation of strength properties, for example by corrosion.

Prakash et al. 2016 identified the following significant wear parts within an analysis on smart-phones. Typically, the following components are seen to be relevant: the display assembly, battery, audio control and power button cable, the power button, the rear case, lightning connector and headphone jack, LCD shield plate and the screen protector. According to the internet platform ifixit.com, it is possible to repair such components. However, barriers such as costs for spare parts and repair can significantly hinder it in practice (see economic obsolescence).

For consumer notebooks, Prakash et al. (2016a) reveal failure to be a potential issue for the following components: hard disc drives, memories, graphics chips and batteries (very commonly), main boards, processor fans, power supplies, peripheral interfaces, screen and screen lids (hinges) and notebook housings (commonly). It is interesting to note that devices used for business purposes (business notebooks) differ to consumer notebooks when it comes to the likelihood of failure of components. On business notebooks, hard disc drives and batteries are shown to fail frequently, though all other components were rarely reported to fail. Principal reasons for the likelihood of failure are thermal issues, mechanical wear and careless handling. Furthermore, permanently fitted batteries, soldered-in memory device components and permanently fitted hard drives should be considered as lifetime-limiting factors. Moreover, the lifetime of installed electrical and electronic components (e.g. aluminium electrolytic capacitors) and assemblies is greatly dependent on the dimensioning of the components and their thermal exposure. Similar issues are expected for tablets as well.

5.2.2. Functional obsolescence

'Functional obsolescence' takes into account fast changing technical and functional requirements concerning a product (e.g. inter-operability between hardware and software). This means that certain functions do not satisfy user's needs after a certain time period anymore as compared to newer functions. For ICT products, empirical evidence (test 2013; Wieser & Tröger 2015) shows that typical reasons for functional obsolescence are a technically limited memory, limited battery life-span as well as the user's wish for more and new functions. The reasons for functional obsolescence are mostly dominated by software-induced factors dominate such as the operating system and driver updates or changes in standardisation landscape. Precisely, it implies that if manufacturers adapt their operating systems only for very specific devices or brands, the effort and cost of providing updates increases substantially. Thus, the intentional termination of software support for a device or an operating system takes place under cost considerations.

This shows that hardware and software strongly depend on variable systems that guarantee the interoperability between both sides. A prominent example is that new operating systems are not compatible with the hardware performance of older ICT devices, even if the latter are still technically functioning. For instance, it was seen that an update from Windows 7 to Windows 8 was not possible due to the heavy modifications in the operating system. An update to Windows 10 was limited due to higher requirements for RAM and storage. Vice versa, a lack of software support for older operating systems can significantly hamper its use on newer hardware.

5.2.3. Economic obsolescence

'Economic obsolescence' describes a decline in performance characteristics of a product because necessary repair and maintenance measures cannot be implemented due to cost reasons. This effect is triggered by the fact that the costs of purchasing a new product, when compared to repair costs, are perceived to be lower. Typical reasons are rapid price decrease for new products, very short product development times, design that hinders repair, high repair costs and insufficient availability of spare parts, special tools and repair services.

In this regard, the integration of batteries in smartphones has been analysed by 'Stiftung Warentest' (test 2013). It showed that in around 36 % of the examined devices in 2013 the batteries could not be changed by the users without using special tools. Stiftung Warentest tested further smartphones in an additional test in 2014, finding that approx. 35% of the devices have a non-replaceable battery. The tests included several models that received a poorer quality rating in terms of battery performance. Due to the fact that users are unable to replace some batteries and that battery performance is inadequate, it seems likely that these models will end up being replaced in the course of their utilisation due to poor battery performance. In this case, it is important to keep in mind that the usage intensity of smartphones/ mobile phones has increased over the years, which means that battery quality and replaceability play an extremely important role.

This combination of low quality of batteries and very intensive use patterns of devices can lead to early failure of such batteries. However, if the latter are not economically changeable by technical staff for reasons such as complicated design/many working steps (see www.ifixit.com) and/or high labour costs for repair staff, the useful lifetime of the whole device is strongly determined by a lock-in effect that entirely depends on the quality of the first battery.

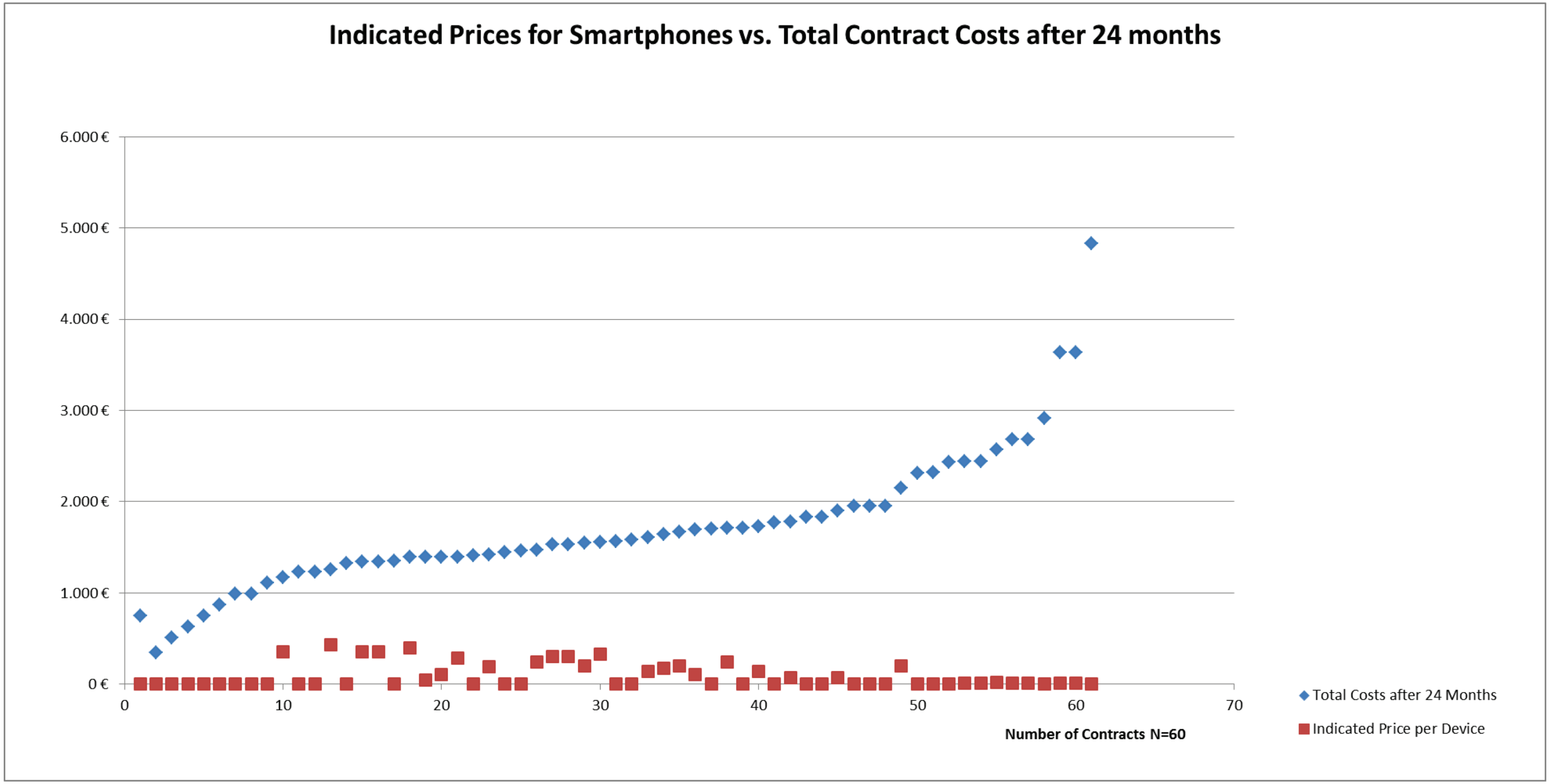
5.2.4. Psychological obsolescence vis-à-vis Business-model driven obsolescence

'Psychological obsolescence' means an early ageing of products due to fashion trends, new technical trends and consumption patterns. It can result in the purchase of a new device even if the previous one is still operating without any problems. This phenomenon has been observed in various studies (Prakash et al. 2016a; test 2013; Wieser & Tröger 2015). A further investigation conducted by Stiftung Warentest shows that just 9% of respondents who changed their mobile phone after a period of less than 3 years cited a battery defect or weak battery performance as the reason for doing so. 68% of respondents on the contrary stated that they change their mobile phone after periods of less than 3 years either because they desire an even better device (40%) or because they regularly receive a new phone through their contract (28%), i.e. psychological obsolescence. Furthermore, other surveys by Stiftung Warentest reveal that 42% of users in Germany replace their mobile phone after a period of less than 2 years. Approx. 16% of users replace their mobile phones every three years. According to Wieser & Tröger 2015, a typical reason for replacing the mobile/smartphone is to 'grant oneself with something [special]'. Consequently, it is very often the user's wish for a new, better product that determines the limitation of usage times.

A second corresponding effect is the fact that users of smartphones and tablets typically perceive that they receive a new ICT product within a new contract package at no or relatively low cost. According to (test 2013), 28% of mobile/smartphone users interviewed indicated that they would automatically receive a new device regularly within 3 years by the provider.

Accordingly, in this study Oeko-Institut provides a short review of current contract models for smartphones in Germany, analysing 60 current contract offers by the three biggest three mobile telecommunication providers dominating the market.

Figure 5-3: The indicated price of a device does not correlate with total contract costs



Source: Own Analysis according to data from t-mobile.de, o2online.de, vodafone.de

Figure 5-3 shows the indicated prices for new smartphones (purchase price) within a contract package (red boxes) compared with the total costs[10] of the contract package (blue diamonds). Firstly, the data shows that in most cases the indicated price of the new device is extremely low compared to the total costs of the contract after 24 months. This means that the perceived price of the new hardware is very low. Secondly, if contracts are designed in a way that the share of the indicated purchase price for new devices is relatively high compared to the total costs, no direct correlation to the total costs could be identified. This means that contracts where higher upfront prices have to be paid for new devices are not cheaper in total. So, there seems to be no economic reason for telecommunication providers to communicate very low upfront prices for new devices. It can just be interpreted as an additional incentive to decide on a new contract after two years (or a prolongation including the new device).

A third result of the analysis refers to contracts that offer a new device after 12 months (11 of the analysed 60 contracts cover a new device after 12 months). Such contracts are significantly more expensive over the contract period. Their total costs of them account for average: 2,432 € in 24 months (including 2 devices), whereas the other regular contracts accounted only for average: 1,756 € for 24 months in total (including only one device). This might be interpreted in a way that for this second device, consumers indirectly have to pay on average around 676 Euro.

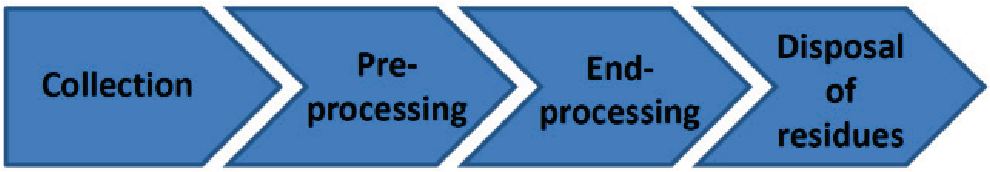
In summary, it can be stated that psychological obsolescence plays the leading role in limiting the usage duration of smartphones/mobile phones. However, the business models of the telecommunication service providers seem to stimulate the psychological obsolescence in smartphones. Thus, the supposedly low purchase prices of most smartphones, hidden in monthly overall contract costs, incentivize consumers to use devices for a short time, leading to a fast exchange rate of devices. To overcome this effect, contract models could be designed in a way that consumers are incentivized to prolong the use phase of their products.

6. Recycling – status and challenges

With regards to electrical and electronic equipment, the term recycling is usually used for all operations that lead to a recovery of embedded materials so that they can be reintroduced into the industrial system. It is noteworthy that in the widely established waste hierarchy, other options, namely waste prevention and reuse, are given priority over recycling[11].

The recycling chain for end-of-life electrical and electronic equipment can be generically differentiated in the steps illustrated in Figure 6-1.

Figure 6-1: Generic recycling chain for end-of-life EEE



Source: Oeko-Institut e.V.

[10] Total costs within 24 month are calculated as the sum of (1) price of the device, (2) initial connection charge and (3) monthly charge for the telecommunication service, multiplied by 24 months.

[11] See Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

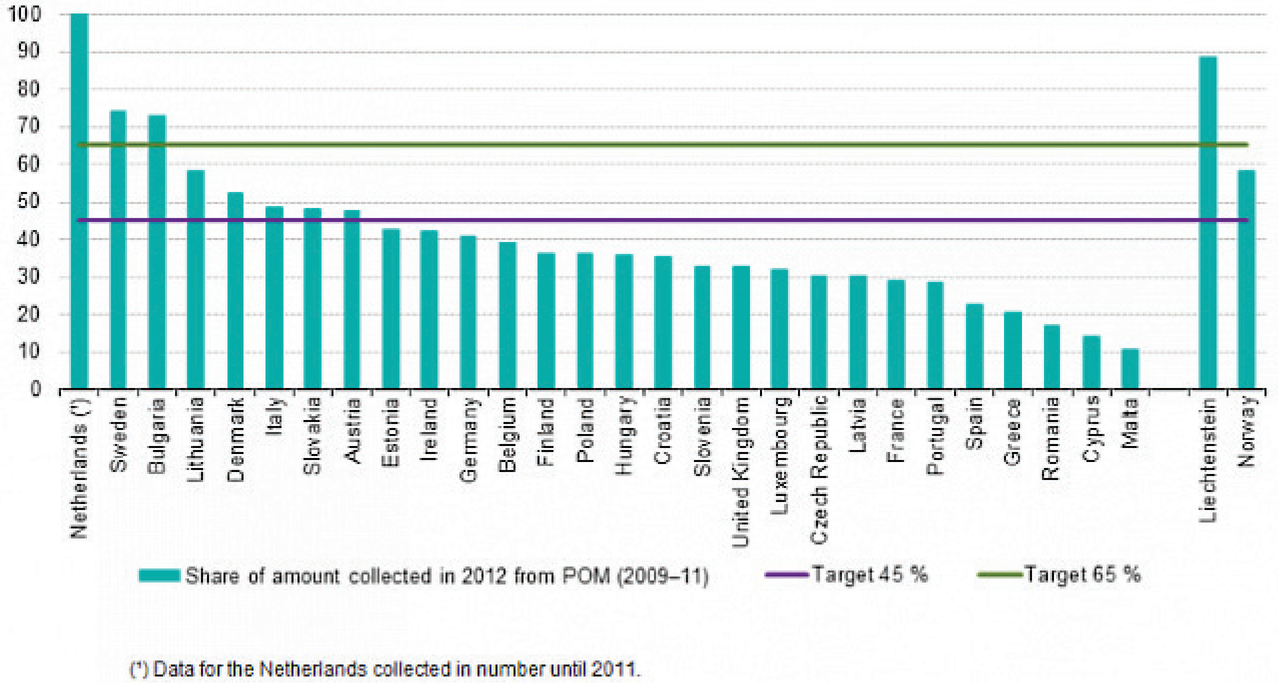
To gauge recycling efficiency in terms of materials recovered in the whole chain, the efficiencies of the first three steps have to be measured and multiplied. The following sections give an overview of these steps with a particular focus on smartphones and tablets.

6.1. Collection

In many regions of the world, the collection of Waste Electrical and Electronic Equipment (WEEE) is one of the most important challenges in the whole recycling chain. This has to do with the fact that collection from households and businesses is costly as it involves quite significant transport and logistics. In order to keep these costs in a manageable range, many countries require private and corporate consumers to support WEEE collection by their own efforts. In most cases, consumers are required to deliver their WEEE to central collection points or to dispose of it using pre-arranged municipal kerbside-collections. Nevertheless, in most regions of the world these systems work imperfectly as many consumers are either unaware of their WEEE disposal duties or are unwilling to make the effort. Subsequently, collection rates are often below 50% as illustrated in Figure 6-2 for EU countries.

It is widely known that this problem of insufficient collection is particularly pronounced for small devices such as smartphones and tablets. Although there are no global statistics available on this issue, data from various authors and regions of the world estimate that global collection rates for end-of-life mobile phones are well below 50% and most probably even below 20% (Chancerel 2010; Geyer & Blass 2010; Hagelüken 2006).

Figure 6-2: Collection rate for WEEE in the EU in 2012[12]



Source: Eurostat (2015)

[12] As a percentage of the average weight of EEE put on the market in the three preceding years (2009–2011).

The reasons for these low collection rates can be summarised as follows:

- As mobile phones and tablets are often perceived as valuable devices even after being taken out of use, many consumers tend to store them in households rather than disposing them. This behaviour is aggravated by the increasing awareness for data security issues. Smartphones and tablets allow access to a broad range of personal data so that many consumers are increasingly reluctant to give away such devices.
- Many consumers give used devices to other consumers as second-hand device – either via direct relations between individuals (e.g. within family), or via specialised second-hand collection schemes and purchase offers.
- As mobile phones and tablets are quite small, it is believed that some consumers dispose these devices in their household waste.

From an environmental perspective, measures leading to an extension of product life-time (reuse) are clearly beneficial (see Chapter 5). Although prolonged storage in households does not have any direct negative impacts on the environment, it represents a loss of opportunities for reuse. This is because the reuse potential of devices decreases over time as they are increasingly perceived as being outdated. Disposal with household waste clearly has clearly negative environmental impacts from both the loss of reuse and recycling potential and the fact that most household waste management systems are not designed for treating the various chemicals embedded in EEE.

Beside collection rates, the quality of collection is also an important factor in the end-of-life management of smartphones and tablets: in order to preserve reuse potential, collection and storage should ideally not expose the devices to physical stress and moisture. In addition, the level of sorting is an important factor for the subsequent reuse and recycling logistics. If smartphones and tablets are mixed with other product groups such as household appliances at the point of collection (see Figure 6-3), the efforts for effective sorting increase significantly.

Figure 6-3: E-waste collection in a German municipality

Household equipment (hoovers, mixer, hairdryers…) is collected together with electronic equipment (computers, hi-fi…)

Source: Oeko-Institut e.V.

Such mixed e-waste deliveries can often not be properly screened for devices for reuse, or be sorted according to pre-processing necessities, particularly in regions with high labour costs (see Section 6.2).

6.2. Pre-processing

Pre-processing encompasses all steps to separate and sort the various embedded materials into output fractions that can be passed-on to end-processing units such as smelters and refineries (see Section 6.3).

Most pre-processing operations start with a sorting and depollution step. The aim of this step is to comply with (often mandatory) depollution requirements such as those laid out in Annex VII of the European WEEE-Directive. With regards to smartphones and tablets, depollution involves a removal of the batteries and external electric cables (chargers). In the EU it is also required to separate liquid crystal displays larger than 100 cm^2, which is relevant for most tablets.

Many enterprises also use this first depollution step to screen incoming WEEE for devices suitable for repair and reuse. As illustrated in Section 6.1, the level of sorting during collection is an important factor determining the effectiveness of depollution and re-use screening. On various site visits to recycling enterprises in the EU, Oeko-Institut found out that deliveries of mixed WEEE mostly undergo quite superficial depollution as labour costs for a more detailed screening and depollution would be too high. In contrast, deliveries of well sorted IT-equipment (e.g. mobile phones only) are economically much more attractive for companies and usually undergo a thorough screening for repairable and reusable items. In addition, the remaining devices often undergo a quite thorough depollution with most batteries being removed for separate treatment.

After this initial depollution, WEEE is mostly broken down into parts and components either by mechanical processes (e.g. shredding), manual operations (dismantling) or a combination of the two. The mixed scrap that is generated is then sorted into the main output fractions (e.g. steel-scrap, aluminium-scrap, copper scrap, printed circuit boards, plastics) that are either passed-on to end-processing units (see Section 6.3) or to specialised companies that conduct more specific sorting (e.g. into various grades of aluminium- or steel-scrap).

Regarding electronic equipment, many mechanical pre-processing steps have the disadvantage that they lead to losses of valuable metals such as gold, silver and palladium (Chancerel 2010; Hagelüken 2006; Salhofer et al. 2009). This can be explained by the fact that mechanical methods "cannot perfectly liberate all materials from complex material compositions so that some precious metals bearing parts and components are still attached to steel, aluminium and plastic parts. In the subsequent mechanical sorting cascade, these conglomerates are to a certain extent sorted into output fractions such as the ferrous metals or aluminium fraction, which are not destined for precious metals recycling (unintended co-separation). Subsequently, a significant share of precious metals contained in EEE is delivered to end-processing units, which cannot recycle precious metals. Furthermore, mechanical stress caused by destructive pre-processing methods can also cause losses of precious metals into the dust fraction" (Möller et al. 2015). In order to reduce the losses of precious metals, mobile phones and comparable devices are therefore – after extraction of the batteries – often delivered directly to end-processing units specialising in the recovery of copper and precious metals.

As already stressed for depollution, such selective treatment of mobile phones also depends on a good level of sorting of incoming WEEE. Devices delivered together with other mixed WEEE are often fed into mechanical shredding and sorting indiscriminately – at least in regions of the world with a relatively high level of labour costs.

6.3. End-processing

With regards to smartphones and tablets, end-processing facilities exist for the following fractions:

- Copper and precious metals
- Rechargeable batteries (Li-Ion, NiMH)
- Aluminium scrap
- Steel scrap

End-processing facilities for steel scrap and aluminium scrap are only relevant for devices that are undergo mechanical pre-treatment. As already indicated in Section 6.2 such mechanical pre-treatment causes losses of precious metals. On the other hand the practice of feeding handsets directly into secondary Cu-smelters leads to losses of aluminium and iron as these metals move into the slag phase of these smelters. Table 6-1 gives an overview on the various recycling options for smartphones and tablets. It shows that some elements such as magnesium, tungsten, rare earth elements, tantalum and gallium are not recovered from EoL devices at all. Although there are industrial recycling capacities for some of these metals (magnesium, tungsten, some rare earth elements, tantalum), these processes require quite pure input material. Thus, recycling of these metals would require an effective separation of the relevant components. Due to the small quantities of these materials in smartphones and tablets, the related efforts are not justified from an economic perspective. One exemption might be the recycling of magnesium, which is used in the casing of some models. Presupposing the delivery of mono-fractions, some recyclers might be motivated to separate the relevant alloys for specific recycling.

Table 6-1 also illustrates that there is no perfect recycling path for smartphones and tablets. Nevertheless, recycling option 2 is widely regarded as the best recycling option as it yields quite high recycling rates for copper, precious metals and cobalt. As the primary production of precious metals is associated with particularly high energy requirements and greenhouse gas emissions per weight unit, this option yields the highest environmental benefit.

Table 6-1: Overview on major recycling options for smartphones and tablets

Material		**Option 1:** Battery is not removed, device fed into secondary Cu-smelter	**Option 2:** Battery is removed, handset fed into secondary Cu-smelter, battery into battery-smelter	**Option 3:** Device (incl. battery) is shredded and mechanically sorted into output fractions which are fed into Cu-, Fe- and Al-smelters
Aluminium	Al	No	No	Partly
Copper	Cu	Yes	Yes	Partly
Cobalt	Co	No	Yes	No
Magnesium	Mg	No	No	No
Tin	Sn	Yes	Yes	Partly
Iron (Steel)	Fe	No	No	Partly
Tungsten	W	No	No	No
Silver	Ag	Yes	Yes	Partly
Rare Earth Elements	REE	No	No	No
Gold	Au	Yes	Yes	Partly
Tantalum	Ta	No	No	No
Palladium	Pd	Yes	Yes	Partly
Indium	In	Partly	Partly	Partly
Gallium	Ga	No	No	No

No = no material recovery.
Partly = recovery of up to 80% of the embedded material
Yes = recovery of > 80% of the embedded material

Source: Own compilation with data from Buchert et al. (2012), Hagelüken & Buchert (2008) and Möller et al. (2015)

6.4. Exports of used and end-of-life EEE

Starting with the first NGO reports on the export of used and end-of-life IT-equipment to China, Nigeria and Ghana (Kuper & Hojsik 2008; Puckett et al. 2002; 2005), the subject of illegal e-waste exports from industrialised to developing countries has been repeatedly covered by various media reports and other investigations. In recent years, international attention has mainly focused on Ghana where e-waste (together with various other metal containing scraps) is dismantled by informal recyclers. Various process-steps by these recyclers (e.g. the open burning of cables to recover copper) are associated with extreme levels of pollution. In addition, fractions of no value for informal recyclers (e.g. plastic cases, lead containing CRT-glass) are disposed-of in an uncontrolled way or even burned to reduce waste volumes (Prakash & Manhart 2010). One main area of such recycling practices – the scrap market in Agbogbloshie in Accra – was ranked as one of the world's worst polluted sites in 2013 (Blacksmith Institute & Green Cross Switzerland 2013).

Nevertheless, more holistic investigations on e-waste generation and management in Ghana revealed that a large portion of the e-waste recycled and disposed in areas such as Agbogbloshie originates from local households and businesses. Although there are deliveries of end-of-life equipment directly from the port of Tema (the most important Ghanaian port for any kind of imports), the majority of imported devices are not going directly to crude recycling, but to repair and refurbishing businesses (Amoyaw-Osei et al. 2011; Prakash & Manhart 2010; Secretariat of the Basel Convention 2011). Amoyaw-Osei et al. (2011) found out that the market-share for used IT-equipment is as high as 50% for many product groups in Ghana. This means that the trade with in equipment is primarily organised to satisfy the local demand for affordable IT-equipment. Of course, the local repair and refurbishing industries generate e-waste: many imported devices do not function and can only be used as a source of spare parts. The residues are usually channelled to informal recyclers such as those in Agbogbloshie.

In terms of the status of imports many shipments are in a legal grey zone: While exports of non-functioning equipment are clear violations of the Basel Convention[13], functioning second-hand equipment of high quality is usually classified as products and not waste. Thus, trade bans of the latter shipments would constitute violations against WTG and GATT rules.

Therefore, various attempts have been made in recent years to draw a clear and practical boundary between devices not suitable for reuse (to be legally classified as e-waste) and second-hand devices (to be legally classified as products). Amongst other things, such requirements are integrated in Annex VI of the European WEEE Directive (see Section 7.1.2). In addition, a working group under the framework of the Basel Convention is currently drafting Technical Guidelines on this aspect. Besides the various shipments in a legal grey zone, there are also shipments aimed at saving disposal costs in other regions of the world. These clearly illegal shipments are mostly organised for e-waste containing a high portion of materials and substances requiring costly treatment in industrialised countries. This is particularly the case for the following two types of devices:

- CRT-devices: The CRT-glass of old TVs and computer monitors contains lead and has very limited recycling applications. In Europe, environmentally sound management of CRT-glass is associated with costs ranging between 26 and 150 Euros per tonne (Bleher 2014). In contrast, in many developing countries CRT-glass is disposed in irregular dumpsites free of charge. This opens the door for CRT-shipments labelled as second-hand equipment for reuse that are in fact motivated to safe disposal costs.
- Refrigerators: Due to the ozone depleting properties of refrigerants and foam-blowing agents of fridges manufactured before 1993, and the global warming potential of many other refrigerants and foam blowing agents, recyclers in industrialised countries have to recover and destroy these gases. This is done in a series of process steps to degas the cooling-circuit, followed by the isolation foams. Subsequently, the captured substances need to be destroyed in certified process (e.g. high temperature incineration). In this situation exports to countries where such management is not required can also save costs.

Additionally, it is likely that some exports of IT equipment are also motivated by criminal networks linked to the skimming of sensitive personal and institutional data.

[13] Full title: Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal

7. Existing improvement strategies

7.1. The legislative landscape

The following sections provide an overview of the most relevant European legislation with regard to resources, substances and materials of electric and electronic equipment. Within this study, it was not possible to elaborate a full picture of international legislation. However, apparent international linkages to the European legislation are briefly outlined.

7.1.1. EU RoHS Directive

The acronym RoHS stands for "**R**estriction **o**f (the use of Certain) **H**azardous **S**ubstances" in electrical and electronic equipment. The current European RoHS Directive 2011/65/EU (RoHS 2) (EU Commission 2011) is a recast of RoHS Directive (2002/95/EC) (RoHS 1) of the European Parliament and of the Council. In contrast to the previous version, the scope of the Directive now includes all types of electrical and electronic equipment (as referred to in Articles 2(1) and 3(a)).

Article 4(1) of Directive 2011/65/EU requires that "electrical and electronic equipment placed on the market, including cables and spare parts for its repair, reuse, updating of its functionalities or up grading of its capacity, does not contain the substances listed in Annex I". These are:

- Lead
- Mercury
- Cadmium
- Hexavalent chromium
- Polybrominated biphenyls (PBB)
- Polybrominated diphenyl ethers (PBDE)

Furthermore the EU has adopted a ban on the use of following four phthalates:

- Bis(2-ethylhexyl) phthalate (DEHP)
- Butyl benzyl phthalate (BBP)
- Dibutyl phthalate (DBP)
- Diisobutyl phthalate (DIBP)

These restrictions will come into force in July 2019 for all electrical and electronic equipment, except medical devices and monitoring and control instruments, which can be placed on the market up to July 2021.

The limits are the following:

- Maximum 0.01% (by weight) for cadmium
- Maximum for each 0.1% (by weight) for lead, mercury, hexavalent chromium, PBB and PBDE, as well for the four phthalates.

Article 5(1)(a) provides a basis for excluding certain applications from these provisions. It specifies the criteria on which such exemptions can be justified: in cases where the environmental and health protection required by Regulation 1907/2006/EC (REACH) (see also Section 7.1.4) is not weakened, exemptions can be granted in cases where at least one of the following criteria is fulfilled:

- their elimination or substitution is scientifically or technically impracticable,
- the reliability of substitutes is not ensured,
- the total negative environmental, health and consumer safety impacts caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

Furthermore, the availability of substitutes; the socio-economic impacts of substitution; any potential adverse impacts on innovation and life-cycle thinking can also be considered to determine the duration of exemptions.

On the basis of these provisions the Commission is receiving requests for applications to be exempted from the requirements of the Directive and for existing exemptions to be amended, renewed or revoked[14]. These requests need to be evaluated in order to assess whether they fulfil the above mentioned requirements of Article 5(1)(a). Where the requirements are fulfilled the Commission can propose a draft decision amending the Annex to the RoHS Directive. Granted exemptions are listed in Annex III and IV of the Directive. Usually, exemptions require revision after a defined time-period of five years; respectively seven years for medical devices and monitoring and control instruments.

While the European Union was the first region to ban lead, mercury, cadmium, chrome-VI, PBB and PBDE from electrical and electronic equipment, the effectiveness of the Directive stimulated other jurisdictions to implement comparable requirements:

- **China RoHS**: The scope includes electrical and electronic equipment with a maximum rated working voltage of 1000 V alternating current or 1500 V direct current. China RoHS currently restricts the same six hazardous substances (without the phthalates) and the same maximum concentration values as the European RoHS Directive. The Chinese Ministry of Industry and Information Technology (MIIT) published a final revised version of China RoHS (Version 2), which came into force on 1st of July 2016 (for more details, see[15]).
- **Korea RoHS[16]**: Electrical and electronic equipment is defined as equipment or devices operated by electric currents or electromagnetic fields. It has been designed to harmonize with the EU RoHS and WEEE directives. The implementation is further orientated towards improvement in product design, recycling and recovery targets for electrical and electronic equipment (EEE) as they become technically and economically feasible.
- **Japan RoHS[17]**: Whereas EU RoHS has a defined focus on restricting certain hazardous substances for one specific industry (electrical and electronic equipment), Japan RoHS is more comprehensive. In 2001 the "Law for the Promotion of Effective Utilization of Resources"[18] seeks to establish a sustainable society based on reduction, reuse, and recycling. Construction companies and electric utilities are targeted as well as a wide range of manufacturers. However, tablets and smartphones are not in scope of this regulation.

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14 Article 5(1)(b) provides that exemptions may be revoked where the conditions set out in article 5(1)(a) are no longer fulfilled.

15 http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c4609634/content.html

16 http://www.korearohs.com/

17 http://home.jeita.or.jp/eps/jmoss_en.htm

18 http://www.meti.go.jp/policy/recycle/main/english/law/promotion.html

- **California RoHS**: The California RoHS regulation came into effect in 2007[19]. The purpose of this law was to limit the amount of certain hazardous heavy metals in specific electronic devices. California RoHS currently restricts only lead, mercury, cadmium and/or hexavalent chromium however those with the same maximum concentration values as EU RoHS.

7.1.2. EU WEEE Directive

The Restriction of the use of certain Hazardous Substances (RoHS) Directive and the European Waste Electrical and Electronic Equipment (WEEE) Directive are linked in principle. The WEEE Directive aims at reducing the amount of waste electrical and electronic equipment destined for landfill (i.e. mainly end-of-life management), whereas the RoHS Directive regulates the use of certain hazardous substances in electrical and electronic equipment (i.e. starting at the design and production stage; see Section 7.1.1).

The European WEEE Directive (2002/96/EC) first entered into force in February 2003. The recast WEEE Directive 2012/19/EU (WEEE 2) (EU Commission 2012b) is effective since February 2014. The main aspects of the Directive can be summarised as follows:

- Article 4 indicates that producers shall design products in a way that it facilitates re-use and dismantling and recovery. While the article is quite open in its wording, it holds a reference to the European Ecodesign Directive (see Section 7.1.5).
- Article 5 requires that WEEE must be collected separate from other waste streams
- Article 6 prohibits the disposal of separately collected and non-treated WEEE. In addition, the Article requires that collected WEEE shall be transported in a way that allows optimal conditions for preparing for re-use, recycling and the confinement of hazardous substances.
- Article 7 specifies minimum collection rates that have to be monitored and achieved by all EU member states. From 2016 to 2019, the minimum collection rate is 45%, from 2019 on, at least 65% of the WEEE volumes need to be collected in each member state.
- Article 8 specifies that separately collected WEEE is required to undergo proper treatment. Amongst other things it is specified that batteries, printed circuit boards of mobile phones, and printed circuit boards of other devices > 10cm^2 have to be removed from any separately collected WEEE for selective treatment (see Annex VII of the Directive).
- Article 11 together with Annex V specifies recycling and recovery targets for collected WEEE. For smartphones and tablets (which are part of the European WEEE category 3 – IT and telecommunications equipment), the minimum target for recycling and re-use is 70%.
- Annex VI lays out criteria to distinguish between EEE and WEEE. These criteria are of particular importance as they are the legal basis to determine whether an export of e-equipment is regarded as a shipment of products or as a shipment of waste. In the latter case, transboundary movements require notification according to the procedures of the Basel Convention. If such notification is missing, the shipment is regarded as illegal. Annex VI also contains a reversal of the burden of proof: amongst other things, exporters of used EEE have to provide certificates of functionality tests to regulatory bodies in the EU.
- Articles 12 and 13 regulate the financing of the costs for collection, treatment, recovery and environmentally sound disposal. The articles specify that EU member states shall ensure that producers have to care for the financing of sound WEEE management. Here, it is noteworthy that the term producer is applicable to all companies that first place EEE onto the European

[19] http://www.dtsc.ca.gov/HazardousWaste/rohs.cfm

market. Thus, it also entails importers and retailers. This provision on financing is the core of European extended producer responsibility (EPR) systems.

Internationally, comparable regulations on the management of WEEE exist in various countries. For example, in China the Regulation on Management of the Recycling and Disposal of Waste Electrical and Electronic Equipment has comparable intentions and requirements. Amongst other things, it stipulates that WEEE should be collected separately from other waste streams and that producers are held financially responsible for the environmentally sound management (Wang et al. 2013).

7.1.3. EU Battery Directive

On 20th November 2013, the European Battery Directive 2006/66/EC was amended by Directive 2013/56/EU (EU Commission 2013e). Amongst other things, this amendment introduced new requirements for the removability of waste batteries from appliances such as smartphones and tablets. It specifies that EU member states shall ensure that

- “[…] manufacturers design appliances in such a way that waste batteries and accumulators can be readily removed.”
- “Where [batteries] cannot be readily removed by the end-user, Member States shall ensure that manufacturers design appliances in such a way that waste batteries and accumulators can be readily removed by qualified professionals that are independent of the manufacturer.”
- “Appliances in which batteries and accumulators are incorporated shall be accompanied by instructions on how those batteries and accumulators can be safely removed by either the end-user or by independent qualified professionals.”

This new Article 11 was motivated by the consideration that degrading battery quality paired with high costs for exchanging these batteries are often regarded as major reasons why electronic devices such as smartphones and tablets are replaced by new models (obsolescence, see Section 5.2). Thus, the amendment aims at stimulating product design where consumers can exchange the batteries of their electronic devices without being forced to refer to the producers’ service infrastructure. As industry representatives argued that an exchange of batteries by consumers can have adverse side-effects on product functionality and safety (e.g. by inserting wrong battery types), the new article 11 also allows for designs where consumers cannot remove the battery themselves, but only by independent qualified professionals. With this reference to independent qualified professionals, it is hoped to stimulate completion for battery exchange services so that consumers’ efforts and costs for battery exchange will drop significantly.

The amendment is widely regarded as an important step in the right direction towards design for longer product lifetimes. Although the demands of advocacy groups (removability of all batteries by end-users) were not fully taken-up in the amendment, the current solution seeks to balance-out the consumer demands and technical aspects of battery exchange.

Nevertheless, it has to be noted that Article 11 of the EU Battery Directive primarily addresses removability during the use-phase of devices. From an environmental perspective, the removal of batteries at the end of the product’s life-time is also of importance as they contain raw materials such as cobalt that can be recycled, presupposing that batteries are treated separately from the rest of the devices (see Section 7.1.2). Generally, the major difference between designs for use-phase removability and design for end-of-life removability can be summarized as follows:

- During the removal of batteries in repair operations, it is of high importance not do damage any other parts such as connectors or electronic components. In turn, the time needed for battery exchange is of secondary importance. In order to avoid damage, processes such as the opening of screws are acceptable.
- In contrast, the removal of batteries for recycling is very time sensitive. Usually, workers charged with opening devices for detoxification and battery removal (see Section 6.2) have very little time to conduct this process step. On the other hand, a certain level of physical damage to components such as connectors is acceptable.

7.1.4. EU REACH Regulation

The REACH Regulation (EC) No 1907/2006 (EU Commission 2006) is the central chemical legislation of the European Union as part of its restrictions on products imported to Europe. REACH stands for **R**egistration, **E**valuation, **A**uthorisation and **R**estriction of **Ch**emicals. Electrical and electronic products need to comply with RoHS (see Section 7.1.1), however more hazardous substances are listed under REACH so that this regulation can additionally affect the design of electrical and electronic equipment such as smartphones and tablet PCs. The regulation has been adopted in order to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry. It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals. REACH introduces requirements on component suppliers to provide substance declarations and comply with substance restrictions when they supply their articles (e.g. components) within the supply chain. Thus, basically every company in the EEE supply chain can be affected by REACH. Main elements are the registration, evaluation, authorisation and restriction of chemical substances. Within REACH, the processes of authorisation and restriction aims to ensure the proper control or replacement of very problematic substances contained in products such as electrical and electronic equipment:

- Within the authorisation process, substances of very high concern are identified. These substances may have serious and often irreversible effects on human health and the environment. Substances identified as Substances of Very High Concern (SVHCs) are listed in the REACH Candidate list (ECHA 2016). They have to be progressively replaced by suitable alternative substances or processes. Substances from the REACH Candidate list can be subjected to authorisation. These substances are listed in REACH Annex XIV together with a substance-specific date after which it is no longer permitted to place a substance on the market or to use it – unless an authorisation for a specific use has been granted by the European Commission.
- If the use of a substance (or compound) in specific articles (which could also include smartphones and tablets), or its placement on the market in a certain form, poses an unacceptable risk to human health and/or to the environment that is not adequately controlled, the European Chemical Agency (ECHA) may restrict its use, or placement on the market. These restrictions are laid down in Annex XVII of the REACH Regulation: "Restrictions on the Manufacture, Placing on the Market and Use of Certain Dangerous Substances, Mixtures and Articles". The provisions of the restriction may be made subject to total or partial bans, or other restrictions, based on an assessment of those risks.

Another important aspect concerns providing information on substances in articles to consumers in the EU. Upon requests by consumers, producers need to provide information on SVHC in their product. This information must be provided free of charge and within 45 days. Amongst other things, there is a support tool for consumer requests that supports the generation of requests using the barcode of the article (http://www.bund.net/themen_und_projekte/chemie/stell_die_giftfrage/anfrage_generator/).

A she second review by the European Commission on the efficiency of REACH is expected in 2017. The ECHA second report on the operation of REACH is foreseen for June 2016. A careful analysis of the authorization procedures has been done by EEB. Amongst other things, it concludes that the candidate list has positive effects as it is an important driver to encourage replacement of SVHCs by companies. However, the study also concludes that currently authorizations are also granted in cases where safer alternatives are available or where the analysis of alternatives is inadequate (EEB 2015).

7.1.5. EU Ecodesign Directive and product specific Regulations

The Ecodesign Directive was originally published in 2005 (2005/32/EU) and revised in 2009 (2009/125/EU)[20], extending its scope from hitherto "energy-using" to so-called "energy-related" products (ErP)[21]. Its aim is to reduce the environmental impact of products throughout their life cycle by setting harmonized minimum standards for their ecological design as well as certain performance indicators.

The Directive is a Framework Directive and does not contain minimum requirements for products in itself. Instead, it provides a framework for formulating such requirements, as well as product information requirements. Only products that fulfil the requirements will be allowed to be sold in the European Union. The Directive prescribes a process and certain criteria for creating the requirements, and establishes EU Member States' responsibility for market surveillance and penalties in case of non-compliance.

The Ecodesign Directive is implemented through product group specific regulations (the so-called Implementing Measures). Art. 15 (2) specifies criteria for choosing product groups to be regulated. Among the criteria are, for example, significant volume of sales and trade, significant environmental impact, significant improvement potential without entailing excessive costs, and the failure of other relevant EU legislation to address the issue properly.

The process for creating Implementing Measures is presented in Figure 7-1. It starts with a three-year *Working Plan*, based on a scientific study and published by the Commission. The Working Plan provides an indicative list of products to be regulated. The first two Working Plans covered the periods from 2009-2011 and 2012-2014. To date (March 2016), the adoption of the 2015-2017 Working Plan and the publication of the supporting study have been postponed for various reasons.

In a next step, for the products in the Working Plan *Preparatory Studies* are conducted, following a specific methodology, the so-called Methodology for the Ecodesign of Energy-related Products (MEErP). The studies evaluate the improvement potential of product groups and suggest possible Ecodesign measures. They may also propose Energy Labeling measures in accordance with the Energy Labeling Directive 2010/30/EU. Relevant stakeholders are invited to provide input and comment on drafts.

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[20] Directive 2009/125/EC of the European Parliament and the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products

[21] This means that the new Directive also gives room for product groups that do not use energy itself, but that have a potentially high impact on the energy consumption of other products and systems (e.g. the role of windows in the energy efficiency of buildings).

For each product group, the Commission elaborates a *Working Document* outlining potential policy options and based on the Preparatory Study. Besides legal minimum requirements and information requirements, the Working Document may also propose a Voluntary Industry Agreement. Stakeholders comment on the document in a *Consultation Forum*. Based on the input, the Commission may revise the draft. It is then voted upon by *Regulatory Committee* (made up from Member State representatives). The *European Parliament or Council* may object within three months, on formal grounds. If there is no objection, the Commission *adopts* the regulation and it enters into force.

Figure 7-1: Process for creating Ecodesign Implementing Measures

Source: Own illustration

The following websites provide an overview of the process and of Implementing Measures currently in force or in the course of being developed:

- Official Website of the European Commission on Ecodesign and other legislation on the energy efficiency of products:
  https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products
- Quick overview of status of product groups:
  www.eup-network.de
  www.eceee.org/ecodesign

Ecodesign Implementing Measures may, in principle, address most relevant environmental aspects of products. Annex 1 of the current Ecodesign Directive (2009/125/EC) names the following aspects:

- Energy consumption;
- Material consumption;

- Water consumption;
- Emissions to air, water and soil;
- Hazardous content; and
- Waste aspects (waste generation, possibilities for reuse, recycling and recovery).

However, the regulations adopted so far focused on energy efficiency in the use phase. Also, the methodology applied in the preparatory studies (MEErP) is best suited to assess energy aspects. However, individual Implementing Measures exist that address issues such as reparability, durability or recyclability.

There have been recent developments to better address material efficiency. For example, several studies were commissioned to explore how material efficiency aspects might be integrated into Ecodesign methodology and policies, including the MEErP (Ardente et al. 2011; Ardente & Mathieux 2012; Mudgal et al. 2013b, 2013a). An evaluation study (Molenbroek et al. 2014) discussed a potential better coverage of non-energy aspects and other life cycle phases than the use phase. The draft study for the 2015-2017 Working Plan includes a supplementary report on possible Ecodesign Requirements for material efficiency (EU Commission, DG Enterprise and Industry 2012). Under the Commission's Circular Economy Package of 2 December 2015, it is planned to "include reparability, durability, and recyclability in product requirements under the next working plans implementing the Ecodesign Directive" as well as "consider proportionate requirements on the availability of repair information and spare parts in […] work on Ecodesign" (EU Commission 2015b).

Furthermore, requirements related to material efficiency have been introduced in various product-specific regulations, e.g. on durability of lamps (EU Commission 2012a), on durability of the hose and motor lifetime in vacuum cleaners (EU Commission 2013c). Marking of the content of certain materials is under discussion in some draft revisions, e.g. for hazardous substances such as lead in displays and for permanent magnets containing rare earth materials in fans. Further, for electronic displays, the draft working documents (still under development) initially proposed requirements on design for recovery and documentation for recycling at the end of life of displays. A detailed overview of existing and proposed Ecodesign requirements related to material efficiency is provided in the draft Ecodesign revision study for washing machines and washer-dryers, Task 1-4 (Villanueva et al. 2015).

Tablet computers fall under the scope of the Implementing Measure for computers and servers (EU Commission 2013b). The measure includes requirements for maximum total annual energy consumption, availability and maximum power demand of sleep mode, power demand in lowest power state and in off mode, efficiency of internal power supply, power management and product information. The only requirement on material efficiency is that the products must bear a note "'The battery[ies] in this product cannot be easily replaced by users themselves" if this is the case.

Mobile phones and smartphones, so far, are not covered by any Ecodesign regulation. This is due to the instrument's current focus on energy consumption in the use phase. Because of their relatively low consumption, these products failed to meet the criteria of significant energy consumption and significant improvement potential. However, they have been subject of a study for the 2nd Working Plan and continued to be subject of the 3rd study to establish the "Ecodesign Working Plan 2015 to 2017" (EU Commission, DG Enterprise and Industry 2012). The latter study indicated that the environmental impact is distributed over the whole product life cycle with a considerable impact in the raw materials extraction and manufacturing phase, whereas the energy consumption in the use phase is less significant. It was proposed to include smartphones for resource efficiency reasons. Currently (March 2016), the Working Plan 2015 to 2017 has not been adopted, so it is not known if these products will fall under the scope of future Ecodesign measures.

In addition, external power supplies for smartphones and tablets fall under the regulation on external power supplies (EU Commission 2009). This regulation sets limits for power demand in no-load condition and minimum active efficiency standards. At the time of introduction, this regulation initiated a remarkable market shift from the quite inefficient linear power supply technology to the more efficient switch mode power supplies. Within the Ecodesign stakeholder processes on power supplies, the issue of standardized charging interfaces also played an important role. Although not covered by the power supply regulation, various mobile phone producers signed a memorandum of understanding to develop standardised chargers for their devices. This attempt was based on the vision that future power supplies can be used for various types of devices, which would be convenient for consumers and could also reduce the total amount of chargers to be produced. Although this effort led to the publishing of a standard on charging interfaces and universal power supplies[22], it has not achieved a significant market penetration as illustrated in Figure 7-2.

Figure 7-2: The variety of common charging interfaces for mobile phones

Source: Oeko-Institut e.V.

[22] Interoperability specifications of common external power supply (EPS) for use with data-enabled mobile telephones (IEC 62684:2011)

7.1.6. Product Environmental Footprint (PEF) initiative of the European Commission

A number of methods and standards exist for the assessment and communication of the life cycle environmental impacts of products (including ISO 14040 and 14044, the ILCD Handbook, PAS 2050 and WRI GHG Product Protocol). This leads to a situation in which information on the environmental credentials of products is often not comparable and can only be correctly interpreted if underlying assumptions, decisions and data sources of a product environmental assessment are made transparent. Even the well-established and standardised LCA method (ISO 14040/14044) in itself does not provide sufficient specificity to ensure results from different assessments are comparable to one another.

Based on this observation, in April 2013 the European Commission released the Communication “Building the Single Market for Green Products, Facilitating better information on the environmental performance of products and organisations“ (2013/196/EU) (EU Commission 2013d) and “Commission Recommendation on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations“ (2013/179/EU) (EU Commission 2013a). Together with the Communication the European Commission published detailed methods for conducting Product and Organisational Environmental Footprints (PEF/OEF). Also, a pilot project was launched to develop sector specific rules for the calculation of PEFs/OEFs (so called Product/Organisation Environmental Footprint Category Rules) and develop further overarching rules and databases, such as for treating allocation in multi-product systems, transportation, packaging, waste, electricity etc.[23]

Essentially, a PEF is an LCA study, with the aim to limit all possible decision points that usually have to be taken when assessing the environmental impact of a product: The exact environmental impact categories to be included are defined, as are system boundaries, allocation procedures, data sources and data quality, types of critical reviews, etc. Thereby, communicated PEF results shall become comparable with one another. Potentially, this would also enable consumer communication (comparable to existing energy labelling but with regard to full life cycle environmental performance) and other legislative actions (e.g. mandatory information requirements, green public procurement). As the whole initiative is still in a pilot phase and a lot of issues unresolved, it is unclear if these objectives can be met.

7.1.7. Conflict mineral regulations

As already indicated in Section 3.1.3, mining and trade of tin ores, tantalum ores, tungsten ores and gold are known to be interwoven with violent conflicts and the financing of armed groups of the region in the eastern parts of the Democratic Republic of the Congo (DR Congo). This situation developed within the Second Congo War from 1998 to 2002/2003, when the abundant mineral resources were first used on a large scale to finance the operation of militia groups in the area. First reports about this link between minerals and conflicts were brought onto the UN-level in 2001. At that time, exploitation and trade of minerals were widely controlled by rebel groups allied with neighbouring Uganda and Rwanda (Manhart & Schleicher 2013). After the end of the Second Congo War, violence and insecurity in the eastern parts of the DR Congo continued until today, as well as the control of various armed groups over mines and trading routes. In 2010 the UN Group of experts on the Democratic Republic of the Congo developed a five-step due diligence approach to deal with this situation. In November 2010, the UN Security Council adopted resolution 1952, which states “calls upon all States to take appropriate steps to raise awareness of the due

[23] http://ec.europa.eu/environment/eussd/smgp/policy_footprint.htm

diligence guidelines […] and to urge importers, processing industries and consumers of Congolese mineral products to exercise due diligence […]" (UN Security Council 2010). The subsequent developments of conflict mineral related policies are characterised by the following initiatives:

- In July 2010, US President Obama signed the Dodd-Frank Act[24] that includes a section on conflict minerals (Section 1502). It contains obligatory due diligence requirements for companies listed and traded on the US-American stock exchange market. According to this Act, such companies need to report annually if their products contain 3TG material[25] that originated from the DR Congo or any of its neighbouring countries. If this is the case, the companies need to file a conflict mineral report describing all due diligence measures taken to avoid that the sourced material contributed to conflict financing and human rights abuses. Companies that can prove that none of the materials of a product had any conflict relation in the DR Congo and its neighbouring countries can label their products as "conflict free".
- In 2011 the OECD published the *Due Diligence Guidance on Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas,* which is now available in the second edition (OECD 2012). The guidance document defines a five-step due diligence framework, which is widely in-line with the concept of the UN Group of experts (see above). The five steps can shortly be summarised as follows:
  - Establish string company management systems;
  - Identify and assess risks in the supply chain;
  - Design and implement a strategy to respond to identified risks;
  - Carry out independent third-party audit of supply chain due diligence at identified points of the supply chains;
  - Report on supply chain due diligence

  In contrast to Section 1502 of the Dodd Frank Act, the OECD Guidance is not limited to the DR Congo and neighbouring countries. Nevertheless, it is also focused on 3TGs, which are the most relevant abiotic resources for conflict financing in the DR Congo.

Based on these developments, the European Commission drafted its own policy approach on conflict minerals in March 2014 (EU Commission 2014). While the draft widely follows the scope and approach of the OECD Due Diligence Guidance, it was widely criticised because of its purely voluntary nature and the fact that it effectively excludes downstream companies[26] from any due diligence requirements. As a reaction, the European Parliament rejected the draft in May 2015 and asked for a mandatory due diligence approach that includes up- and downstream industries (European Parliament News 2015). To date (March 2016), the final direction of the planned EU policy is still unclear.

Generally, it is widely accepted that the Dodd-Frank Approach of trying to achieve 100% conflict free supply-chains also led to some unintended side-effects. Amongst other things, one criticism is that such an approach bears the risk of de-facto embargo situations, which are not suitable for stabilising fragile and post conflict areas. Furthermore, the efforts taken to achieve the certification of "conflict-free" status mostly do not stimulate any investment in the Central African Region. On

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24 Full title: Dodd-Frank Wall Street Reform and Consumer Protection Act.

25 3TG = Tin, Tantalum, Tungsten, Gold, including ores containing these metals.

26 In the debate around conflict minerals, industry players are often classified according to their position in the supply chain: While all players from mining to smelting are classified as "upstream companies", all industries active in any process after the smelting stage are classified as "downstream companies".

the other hand, the positive effects of supply chain due diligence are also obvious as its introduction has rapidly changed the global raw materials markets in that many buyers now routinely ask for labour and human rights information from their suppliers. Amongst other things, it is reported that these measures have led to a significant decline in the price of non-certified minerals from the eastern DR Congo, which also means that it effectively has become more difficult to use such minerals for rebel financing (Manhart & Schleicher 2013).

7.2. Voluntary initiatives

7.2.1. Responsible sourcing of raw materials

As a consequence of the discussion around conflict minerals (see Sections 3.2.3 and 7.1.6), various industry initiatives emerged aiming to address the problems around conflict financing and human rights issues. Generally, these initiatives can be classified as follows:

Initiatives to certify 3TG material from the DR Congo and neighbouring countries: As illustrated in Section 7.1.6, industry using 3TG material that originated from the DR Congo and its neighbouring countries are called to conduct supply-chain due diligence. While such measures are mandatory for companies traded on the US-American stock exchange market, many suppliers of these companies are de facto also forced to comply in order not to lose their US-American customers. In this situation, the London-based International Tin Research Institute (ITRI) launched the Tin Supply Chain Initiative (iTSCi). Under this initiative, ores mined in the DR Congo and its neighbouring countries that are proven not to be interlinked with conflict financing and human rights abuses can be certified and sold to smelters globally. The system uses a quite pragmatic bag-and-tag system: ores mined in a conflict-free mine are filled in bags, which are closed with seals carrying an identification numbers. With these numbers, the ore-bags can later be traced-back to its sources. Due to this pragmatic approach, the system has by far the biggest market share amongst the 3T-trading systems aiming to supply conflict free ores from the African Great Lakes Region. Therefore, iTSCi is currently one of the few existing certification systems that allow the sourcing of 3T material from the DR Congo and its neighbouring countries in a manner that is compliant with Section 1502 of the Dodd-Frank Act. Nevertheless, the system is also criticised for the following reasons:

- There are various documented cases where unused iTSCi seals were traded on the black market in the region (UN Group of Experts on the DR of the Congo 2015).
- The iTSCi system as stand-alone only focuses on traceability and assessment of conflict risks in the mining areas. Thus, it does not address broader development targets such as basic health & safety standards, community development and fair remuneration.
- The costs for using the iTSCi systems were repeatedly criticised for being too high (Manhart & Schleicher 2013; Villanueva et al. 2015).

Although there are alternative and more holistic certification systems established or under development, in particular the Certified Trading Chains Initiative (CTC), they not yet gained significant market shares in the region (Manhart & Schleicher 2013).

Certification of smelters and supply-chains: Within the attempts to become compliant with Section 1502 of the Dodd-Frank Act and to avoid the use of conflict minerals, the Electronic Industry Citizenship Coalition (EICC) and the Global e-Sustainability Initiative (GeSI) initiated the Conflict Free Smelter Programme (CFS) in early 2011. It is based on the consideration that the complexity of 3T supply chains is comparably low at the smelting stage. In contrast to miners, oretraders and also the subsequent manufacturing industries, the global number of smelters for tin, tantalum and tungsten is quite small. In addition these smelters are all registered and well known on the commodity market.

Thus, CFS is an industry driven approach where smelters can get certified as "conflict free". For this status, smelters have to annually prove that all deliveries during the past 12 months did either not originate from known or plausible conflict regions, or carry a certification such as iTSCi (see above). With the label "conflict free smelter", all outputs of such smelters can also be termed "conflict free" – at least within the definitions of the Dodd-Frank Act (see Section 7.1.6). A comparable certification system also exists for the gold market (Manhart & Schleicher 2013). While such systems are required for industry compliance with Section 1502 of the Dodd-Frank Act, they can also have a problematic side, as the status of being a "conflict-free smelter" can be achieved quite simply by not purchasing any ores from the African Great Lakes Region. As indicated in Section 7.1.6 such reactions can result in de-facto embargos with negative side-effects in post-conflict situations.

Initiatives to improve social and environmental conditions in mining: In order to avoid de-facto embargo situations for ores from the African Great Lakes Region, a couple of initiatives were set-up to support conflict-free and sustainable mining on the ground in the DR Congo, most notably Solutions for Hope (SfH) and the Conflict-Free Tin Initiative (CFTI). While the first one was fully initiated by the electronics industry, the second one is a public-private partnership between the Netherlands Ministry of Foreign Affairs and various electronics companies.

Despite some on-the-ground problems, both initiatives are widely seen as positive examples of responsible sourcing of materials from conflict affected and high risk areas and clearly go beyond industry compliance efforts.

Use of secondary raw materials: As a reaction to the various environmental and human rights issues in the mining of raw materials, an increased use of secondary raw materials is often seen as a cornerstone of potential solution strategies. This is clearly the case when regarding the total material cycles on the level of national and regional economies: An increase of the total recycling rate will definitely take pressure off mining. Nevertheless, such strategies cannot be simply broken down onto the level of products: although an increase in recycled content of a product seems a plausible strategy, such benchmarks only make sense for selected materials such as paper, cardboard, glass and plastics. For such materials recycling is often associated with a loss of quality, which is sometimes referred to as 'downcycling'[27]. In order to support the recycling market of such materials despite quality losses, various approaches (e.g. ecolabels) try to promote the use of such secondary raw materials in products.

On the other hand, for materials that can be recycled without loss of quality (e.g. most metals), above average recycled content on a product level do not necessarily have any significant effect on the raw material market: As customers are usually not willing to pay premium prices for secondary raw materials, the decision to selectively purchase more secondary raw materials will most likely not stimulate any additional recycling. In turn, it will most likely lead to a situation where other market segments will – without knowing – consume a lower share of secondary material.

Thus, for smartphones and tablets, the use of secondary raw materials primarily makes sense for plastics used in housings, and for paper or cardboard used for packaging.

[27] Although improved sorting can widely reduce downcycling-effects in many cases, the market is still often reluctant to use such materials as it is feared that high quality secondary materials are not available at sufficient quantity over longer time periods.

7.2.2. Best-environmental management options in manufacturing

The European Commission is currently developing guidance on the Best Environmental Management Practice (BEMP) in the context of EMAS, i.e. the EU Eco-Management and Audit Scheme. The aim is to help companies in the EEE sector to identify relevant, proven and reliable technical information in order to continuously improve their environmental performance, especially when registered under EMAS. Against the background of the key drivers of energy consumption and climate change in the manufacturing of electronic devices mentioned in Section 4.2, the following approaches are highlighted (cf. Möller et al. 2015):

(1) **Energy efficient cleanroom technology**: When energy efficient cleanroom technology is designed, a best practice strategic approach considers both technology-related and design-oriented measures. Firstly, optimised sizing of the cleanroom and appropriate adjustment of key operational parameters is taken into account. For example, the air change rate (ACR) can be set to the lowest possible value for the required air quality. Secondly, the removal of excess heat load from process equipment by local in-built means can be implemented (e.g. by using heat exchanges, preheat coils etc.); the recovered heat can then be used for outside air preheat, supply air preheat etc. Finally, highly efficient components (variable frequency drives, premium efficiency fan motors) can be installed for the cleanroom system. Moreover, the upsizing of passive components like filters, dusts and pipes may allow the use of smaller fans and pumps. Overall, a potential reduction of about 50% can be achieved whereas the corresponding CO_2 emissions follow the same reduction rate.

(2) **Rational and efficient use of compressed air**: Based on a first mapping and assessment of the use of compressed air in the manufacturing processes, best practice to optimise compressed air systems starts with identifying and eliminating leaks using appropriate control technology. Many leaks can be located even by simple methods of sensory perception. In order to detect the network leaks in inaccessible areas and within production equipment, an ultrasonic testing device is very effective. Within a second step, the overall energy efficiency of the compressed air system can be increased by checking the existing compressed air system regarding its bottlenecks, unsuitable fittings or hose couplings. An important aspect to consider is whether a centralized compressor station is more suitable than two or more decentralized units. In addition to this, the system design should be based on the annual load duration curve using unregulated compressors for base load and smaller regulated devices for peak loads and minimal load periods. A third step aims to increase the specific energy efficiency of major compressed air system components. The different possibilities in terms of compressor technologies need to be evaluated in order to reach the highest overall efficiency for compressed air generation. Particular attention should be given to supply at part-load. Finally, implementing waste heat recovery can be considered. In terms of technology, this can be achieved through the installation of a plate heat exchanger within the oil circuit of the compressors. The waste heat (at temperatures in the range of 60-80ºC) can be used, inter alia, for space heating or drying of products. Implementing these measures allows achieving relevant energy savings; reduction in energy use of up to 66% are reported (VDMA 2005).

(3) **Energy efficient cooling technology**: The most efficient cooling is one that is not needed. Hence, in best practice, the assessment and optimisation of the required temperature level for processes and rooms with cooling energy demand would be the first step. In terms of rational use of cooling energy, cooling cascades can provide interesting possibilities. By splitting the existing cooling circuit into two or more temperature levels, a large potential for energy savings can be exploited. Furthermore, it is necessary to analyse whether the required cooling energy

has to be provided by compression chiller units (being currently the technological baseline for cooling energy at low temperatures) or whether alternative cooling techniques can be applied. In this respect, especially free cooling techniques are worth giving further consideration. There are many different free cooling systems; in particular the dry cooling and wet cooling are the most relevant as well as the combination of both. Another interesting technological alternative to compression chiller can be seen in absorption technology. Instead of electricity, this technology uses heat source (preferably from waste heat) in order to provide the thermal compression of the refrigerant. Substantial lower electricity demand can be achieved; in particular, it has been reported that free cooling contributes to 75% savings as compared with the compressor chilling unit option.

(4) Energy efficient soldering: The basic approach for improving the environmental performance of soldering processes (especially reflow soldering) is to maximize the throughput of existing equipment, i.e. its conveyor speed. In this respect, the main challenge is to deal with the resulting shortened process time. For this purpose, special profiling software exists that helps to search a large variety of possible combinations, before recommending the maximum possible conveyor speed. Secondly, existing soldering systems can be equipped with retrofit insulation. However, the consideration of heat losses has to be made with respect to the process requirements. A general increase of the thermal resistance achieved by better insulation does not necessarily lead to a lower energy demand. The more insulation is applied, the more relevance can be identified at the level of (usually metal-based) thermal bridges. As the most comprehensive approach, the installation of new reflow soldering equipment can be considered. New reflow soldering equipment is characterized by improved power management system (providing both stand-by and dormant mode), the use of efficient direct-current fan motors, the use of a cooling unit enabling waste heat recovery and optimised use of liquid nitrogen. Best practice new reflow systems are characterised by at least 20% lower electricity consumption, resulting in annual savings (when assuming a 3-shift operation) of approx. 26,000 kWh and reductions of CO_2 emissions of up to 12 tons per year (Bell et al. 2013).

(5) Minimising perfluorocompounds emissions: In best practice, the starting point for minimising PFC emissions during production is the optimisation of existing processes. This refers to the adjustment of process parameters of CVD chambers like chamber pressure, temperature, plasma power cleaning gas flow rates and gas ratios. A reduction in emission of up to 73% can be achieved with this approach. In addition to this, a substitution of currently used PFC gases should be evaluated: A typical example is the replacement of C_2F_6 by C_3F_8, whereas the latter has a significantly (approx. 30%) lower specific GWP (Greenhouse Warming Potential). Besides this, a very effective approach is considered to be the implementation of remote plasma cleaning technology. This process uses NF_3 (nitrogen triflouride), which is immediately dissociated by an external plasma source into fluorine radicals. When fed into the CVD chambers, these radicals convert silicon-containing compounds into silicon tetrafluoride (SiF4). Since a conversion factor for NF_3 of up to 99% can be reached while no recombination of PFCs is taking place, the remote plasma cleaning technology is considered to provide almost PFC-free exhaust gas qualities after treatment. For the process of plasma etching, abatement can be achieved with a small plasma source that effectively dissociates the PFC molecules reacting with fragments of the additive gas (such as H_2, O_2, H_2O, or CH_4). As a result, low-molecular-weight substances like HF with little or no GWP are created. They can, however, be removed by wet scrubbers Similar to remote plasma cleaning technology, emissions reduction efficiency of point-of-use plasma abatement during plasma etching is estimated at 95%.

(6) **Substitution and optimised use of VOC-based solvents**: Substitution of VOC-based solvents can be achieved by using semi-aqueous chemicals. For example, dilute acid formulations of sulphuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) have been employed successfully in the semiconductor industry to achieve effective etch-residue removal, silicon oxide vias, and open bond pads (Sohn et al. 2005). Another promising approach for the optimised use of VOC-based solvents is their on-site recovery. As collection medium, usually activated carbon is used because it is the most versatile of all adsorbents. The reason for this can be seen in its broad pore size distribution and pore volume, which makes it suitable for virtually any process generating solvent-laden air. Carbon adsorption technology can achieve removal efficiencies of more than 99.9%. After adsorption with the solvents, the activated carbon is regenerated with steam, followed by a chilled fluid condensation and packed bed fluid scrubbing to remove and recover the solvents from the exhaust air. Depending on the process requirements, these solvents may be reused in the same process, thereby generating substantial savings over other emission control methods that destroy the solvents (Megtec no date). Solvent recovery is particularly applicable where the quantity of solvents is large, the value of the solvents is high, or the solvents contain chlorine, bromine, fluorine or nitrogen.

Further details concerning the applicability as well as operational data of the approaches mentioned above is given in Möller et al. (2015). This report also contains illustrative examples for several other front-running approaches in terms of voluntary improvement of best environmental management practice during the manufacturing stage of ICT.

7.2.3. Addressing labour and human rights issues in manufacturing and assembly

(1) **Code of Conduct by the Electronic Citizenship Coalition (EICC)**: The EICC is an alliance of numerous prominent manufacturing companies of information and communication technologies (ICT) including their suppliers (EICC 2016). It aims at improving labour conditions within manufacturing of electronic products. In general, the code requires (1) that the employment is chosen freely, (2) child labour (under age of 15) is not used in any stage of manufacturing and young workers (under age of 18) must not perform work that is likely to jeopardize health and safety including night shifts and overtime, (3) working hours do not exceed 60 hours per week, (4) wages comply with applicable law such as minimum wages, overtime and legally mandated benefits, (5) human treatment is guaranteed (no sexual harassment, sexual abuse, corporal punishment, mental or physical coercion or verbal abuse), (6) non-discrimination such as race, colour age, gender etc. compare (EICC 2016), (7) freedom of association in *conformance with local law* including the right of all workers to form and join trade unions. Furthermore there are several requirements on health and safety (amongst others occupational safety), environment (e.g. environmental permits and reporting) and ethics (such as business integrity).

Many NGOs criticise the Code of Conduct as it refers to national law rather than international standards of the International Labour Organisation (ILO) with regards to several requirements such as Freedom of Association (Heydenreich & Görges 2009). Apart from an “encouragement of participants to go beyond legal compliance drawing upon internationally recognized standards” (EICC 2016), this did not change in the current code of conduct that entered into force in January 2016. Accordingly, the GoodElectronics Network, expressing its dissatisfaction with the EICC, called upon EICC member companies to address 5 pressing issues (SOMO 2016):

- Provide supply chain transparency and accountability
- Make the EICC Code of conduct in line with ILO standards

- Respect workers' rights to form & join trade unions
- Ensure the setup of effective, accessible grievance mechanisms
- Engage stakeholders in the decision-making process

(2) **Electronics – Tool for Accountable Supply Chains (E-TASC) by the Global e-Sustainability Initiative (GeSI)**: E-TASC is an online tool for suppliers of information and communication technologies (ICT) developed by GeSI aiming at providing a solution for sustainability within the supply chain. Especially, it shall address an effective implementation for assessing and monitoring suppliers' Corporate Social Responsibility (CSR). The focus is set on the identification of supply chain risks and to drive performance. E-TASC provides guidelines on the (1) environment, (2) ethics, (3) health and safety, (4) labour and (5) management (GeSI 2016). With regards to labour, the guidelines shall help promote safe and fair working conditions and companies are encouraged to implement the requirements. Furthermore, companies shall take "all responsible measures to promote secure compliance with the guidelines with their suppliers, sub-contractors and employees" (GeSI 2016).

In more detail, the labour requirements of E-TASC refer to[28] (1) providing an issue of the contract to employees including working hours and guaranteed wage, overtime pay rates, payment and frequency, notice period, (2) a strict prohibition of child labour (age <15 years) (3) a strict prohibition of forced, bonded and compulsory labour as well as slavery and human trafficking, (4) working hours and overtime according to local law (if no local law is applicable, E-TASC refers to a 8-hours day or a 48 hours week according to the ILO Convention and compensation of overtime at a premium rate according to SA8000 (see below), (5) fair and "reasonable" wage to employees in compliance with legal and industry minimum standards, (6) disciplinary Practices, (7) discrimination, (8) freedom of association and rights to collective Bargaining.

Like the EICC Code of Conduct, E-TASC generally refers to national law and only partly refers to internationally recognised ILO-Standards. This holds for example for the requirement on working hours (see above).

(3) **Social Accountability 8000 – International Standard (SA 8000: 2014)**: The SA 8000 International Standard is a standard that aims at the identification of suitable management systems and certification of compliance with regards to labour standards of suppliers. It was firstly issued in 2001 by the NGO Social Accountability International. Recast versions were published in 2004 and 2008. The latest standard is from 2014. Participation is voluntary (SAI 2014).

In contrast to the EICC code of conduct and the GeSI E-TASC tool, the SA8000:2014 standard refers fully to the ILO Conventions. This holds true for the 8 ILO Core Conventions such as Convention 29 (Forced Labour), Convention 87 (Freedom of Association), Convention 98 (Right to Organise and Collective Bargaining), Convention 100 (Equal Remuneration) and 111 (Discrimination), Convention 105 (Abolition of Forced Labour), Convention 138 (Minimum Age Convention), and Convention 182 (Worst Forms of Child Labour). Beyond this, it includes principles on health and safety, disciplinary practices, working hours, remuneration and management practices.

It is noteworthy, that the SA8000 standard (other than the EICC Code of Conduct and E-TASC) aims at a feasible implementation of the Principle on Freedom of Association and Right

[28] This list is not complete. For all details see GeSI (2016).

to Collective Bargaining. Even in situations where these freedoms are restricted by law, the standard *not only encourages but requires companies* to practically ensure for example that workers can freely elect representatives or to that the workplace is one where workers can fully and without fear of retaliation exercise the right for collective representation.

Summarizing, the SA8000:2014 standard is the most ambitious framework with regards to labour and human rights issues in manufacturing and assembly.

7.2.4. Approaches to extend product life-time

In the following various voluntary initiatives to extend product life-times are summarized.

7.2.4.1. Robust and repair-friendly product design

(1) There are various *voluntary standards* for robustness of ICT products (Dodd et al. 2014). Regarding notebook durability they mainly relate to 'rugged' and 'semi-rugged' laptop specifications. Such notebook tests are mainly defined with reference to the US Department of Defence's MIL-STD-810G test standards (Endpoint Technologies Associated 2008/2011). Both terms can be regarded as durability benchmarks for notebooks according to the MIL-STD-810G test standards (US Department of Defence 2008) and IP65 (Ingress Protection) standards (Dodd et al. 2014; UL LLC no date). Accordingly, the associated performance benchmarks for 'semi-rugged' relate to (1) Drop, (2) Vibration, (3) Shock, (4) Pressure at varying altitudes, (5) Temperature over a range between –29°C to +60°C (6) Temperature shock and (7) Humidity. Also other benchmarks like 'business rugged', 'rugged' and 'ultra-rugged' are defined by the standard. The latter reflect significantly higher product costs as they are specially designed tor military and field applications. Several ICT manufacturers (such as HP, Lenovo, Dell) refer to the MIL-STD-810G test, others refer to own internal standards.

The applicability of the abovementioned durability standards for smartphones and tablets need to be analysed in detail.

Apart from that, durability standards can also be implemented at the level of components. For instance, the current technical background report of the EU-Ecolabel proposes 7 hours of minimum battery life after the full charge using the benchmarks Futuremark PCMark 'home' scenario for consumer products and the BAPCo Mobilemark for business products. Moreover, the technical background report proposes that the models (incl. tablets) in which batteries can be changed without tools shall maintain 80% of their declared initial capacity after 750 charging cycles. Models in which batteries cannot be changed without tools shall maintain 80% of their declared initial capacity after 1,000 charging cycles. This performance shall be verified for battery packs or their individual cells according to the IEC EN 61960 'endurance in cycles' test, to be carried out at 25oC and at a rate of either 0.2 It A or 0.5 It A (accelerated test procedure) (Dodd et al. 2014).

(2) The Fairphone Initiative (www.fairphone.com) launched the second generation of a modular fairphone, Fairphone 2, in the latter half of 2015. While the first Fairphone featured only a limited set of environmentally optimised design features (such as the exchangeable battery and Do-It-Yourself reparability), the second generation of the Fairphone was deliberately designed so as to improve its environmental performance. The main feature in this regard is modularity, which is expected to increase the longevity of the device as it enables the user to easily repair and upgrade the product. In this model, it is relatively easy to dismantle and exchange a large number of components, such as display, battery, front camera, rear camera, earphone outlet etc. (Computer Bild 2015). Smaller modules can be removed using a standard #0 screw driver (iFixit 2016).

7.2.4.2. Repair services

(1) Apart from the aspect of modularity described above, the Fairphone Initiative operates a repair, return & recycling policy that can be summarized as follows. A first option is to ask online for support selecting the “repair/replace” category. In a second step, contact with Fairphone’s *Service Center* shall be established. According to Fairphone, its experts can assess the damage and possibly repair the device. The prices for the repair of components are *fixed* by the Service Center and can be taken from the website. For example, a display assembly replacement accounts for 71.50 € material costs resulting in total costs of 132.93 € including handling and shipping. The second option is a “Do it yourself” (DIY) option, where Fairphone cooperates with the repair platform www.ifixit.com. It includes advice for and an offer of the necessary spare parts. The partner ifixit then offers various repair manuals and youtube videos for Fairphone components.[29]

(2) The mentioned repair platform ifixit.com has developed a *reparability index* for ICT products. A device that is ranked at full score is supposed to be easy repairable at a reasonable cost as a manual is available and disassembly is easy. The score depends on the difficulty of opening the device, the types of fasteners found inside and the complexity of an exchange of major components. Extra points are given for upgradeability, the use of common screws and modularity of components. The ranking for various devices is transparently available on fixit’s website and, hence, can be useful as criterion for consumers’ purchase decisions.[30]

7.2.4.3. Take-back and refurbishment / re-use services

(1) Professional refurbishers, such as AfB, bb-net and GSD, offer second-hand ICT business products which are tested and cleaned. The majority of equipment is upgraded and contains a freshly installed operating system as well as a warranty. Some of the professional refurbishers, such as AfB, also employ a large number of people with handicaps.

(2) Also, telecommunication providers themselves run projects for collection, re-use and recycling of ICT devices such as mobile phones. A few telecommunication providers work together with NGOs and/ or recycling partners to promote the voluntary take-back systems, test for re-use, safe data wiping, refurbishment, re-sale and recycling.

For example, Deutsche Telekom offers a take back system together with the NGO Deutsche Umwelthilfe e.V. End-of-life devices can be handed in at Telekom shops or sent via mail. In turn, Deutsche Telekom provides vouchers that can be converted when new devices are purchased (Deutsche Telekom AG no date). According to the company, the devices are collected and transported to a Recycling Center, where they are recorded and tagged. Finally, it is decided whether the device can be re-used or transferred to material recycling processing. As per the company’s information, in case of re-use, data is fully erased. The re-use rate is reported to be around 10%.

Vodafone also runs a take-back system for mobile phones cooperating with a recycling partner where a re-use check is carried out according to Vodafone GmbH (no date). After refurbishment and data deletion of suitable devices, they are transferred to developing countries. However, it has to be highlighted, that re-use in developing countries is often connected with serious health impacts and pollution problems in the respective countries due to a lack of suitable recycling infrastructure (Prakash & Manhart 2010).

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[29] ifixit.com also provides numerous repair manuals and videos for devices of other manufacturers.

[30] For comparing e.g. smartphones visit: https://www.ifixit.com/smartphone-repairability?sort=score

Finally, Telefónica Germany GmbH (known as the provider “O2”) also operates a return system for mobile phones, smartphones and tablet PCs (Telefónica Germany GmbH & Co. OHG no date). Accordingly, Telefonica cooperates with the above mentioned company “Arbeit für Behinderte”, AfB (http://www.afb-group.de/en), where a re-use check and data deletion is carried out. Refurbished devices are re-sold at AfB shops, devices that are not suitable for re-use are transferred to precious material smelters.

7.2.4.4. Device-independent contract packages

An important trend that is decoupling devices from costly contract packages (see above, Section 5.2) are so called SIM-only telecommunication contracts (Manhart et al. 2012). Apart from direct standard contract packages of telecommunication providers, numerous independent providers offer contracts that do not contain the physical device. As a result, replacement cycles are not determined by contract conditions. Also, if the device is used independently of common combined contracts, there is a strong incentive for the user to take care of the device and use it as long as possible.

7.2.5. Initiatives on sound end-of-life management and recycling

As described in Section 7.1.2 producers (mostly being defined as all companies that first place EEE onto a market) of mobile phones and tablets are in many countries tied into legislative frameworks on sound collection and recycling of electrical and electronic devices. In most cases, this legislative framework is based on the principle of extended producer responsibility (EPR). Thus, in many countries producers are already mandatorily involved in organising and/or financing the collection and recycling of end-of-life devices. But as collection rates for devices like smartphones are mostly far from being satisfactory (see Section 6.1), many producers and network providers launched temporary or permanent collection campaigns. As the number and variety of such initiatives is large, the following list provides a generic overview about the most common types of such collection campaigns:

- Many producers and network providers offer trade-in models: Customers that hand-in an old mobile phone are granted a discount for the purchase of a new device and/or service agreement.
- Producers and/or network providers have repeatedly launched campaigns to motivate consumers to hand-in obsolete mobile phones. In most cases, this type of campaign provides a temporarily limited collection infrastructure (e.g. in schools, shopping malls) and is often paired with an information campaign and references to the environmental importance of recycling.
- Comparable campaigns have also been organised by non-industry organisations such as NGOs and municipalities.
- There are various internet based purchase offers for used smartphones and tablets. Depending on the age and quality of devices, these systems offer monetary incentives for many (but not all) models. These initiatives are usually based on business models tied to refurbishing and sale to a second-hand market.
- Some producers launched mobile phone collection initiatives in countries not yet subject to any e-waste related legislation (e.g. developing countries). Some of these campaigns introduced an incentive system (e.g. cash payments of each collected device) to attract relevant volumes of end-of-life devices.

7.2.6. Fairphone

In 2013, the social enterprise Fairphone with headquarter in Amsterdam released its first edition of the Fairphone. The aim of the enterprise is not to gain high market-shares, but to demonstrate that the problems illustrated in the chapters above can at least partly be mitigated by adequate steps. The production of the Fairphone 1 and the Fairphone 2 were financed by consumers who were willing to pay the purchasing price long before receiving the device.

Although the Fairphone models hold no independent ecolabel (see Section 7.2.7) or fair-trade certification, the initiative successively implements various measures to improve the sustainability profile of its models:

Fairphone 1:

- Possibility to use two SIM cards in the same device (to avoid the need for consumers to use two phones when using two different phone numbers)
- Use of capacitors with tantalum from the Solutions for Hope (SfH) project in the DR Congo (see Section 7.2.1)
- Use of tin from the Conflict-Free Tin Initiative (CFTI)[31] (see Section 7.2.1)
- Approaches to improve conditions for assembly workers in China (see Section 7.2.3)
- Fairphone finances the collection of end-of-life mobile phones in Ghana (see Section 7.2.5)
- Product design for easy battery removability (both, use-phase and end-of-life removability) (see Section 7.1.3)

Fairphone 2:

In addition to the measures already taken for Fairphone 1, Fairphone 2 is characterised as follows:

- Use of certified gold
- Longevity, modular design and high reparability (Fairphone 2 received the ifixit reparability score of 10/10, see Section 7.2.4)

Another important characteristic of the Fairphone initiatives is their aim to increase transparency in the supply chain. For instance, it has published a detailed breakdown of the costs of making Fairphone 1 and 2. Furthermore, Fairphone has been quite transparent in highlighting the challenges and bottlenecks in achieving improvements in the supply chain.

7.2.7. Voluntary Ecolabels for tablets and smartphones

In a mix of policy instruments, voluntary eco- or sustainability labels are important to pull the market towards more sustainable products. They often comprise ambitious requirements related to the manufacturing, use and end-of-life phases of products. For ICT products, relevant ecolabels are EPEAT (International), TCO (International), EU Ecolabel (Europe), Nordic Swan (Nordic EU countries), and Blue Angel (Germany)[32]. As the manufacturing and end-of-life management of for

[31] In contrast to the use of certified tantalum, the use of certified tin follows a mass-balance approach. This means that the tin contained in the device might not physically stem from the CFTI mines in the DR Congo, but Fairphone ensures that an equivalent amount of tin from CFTI mines was delivered to a cooperating smelter.

[32] cf. www.epeat.net; www.tcodevelopment.com; http://ec.europa.eu/environment/ecolabel/; www.nordic-ecolabel.org; https://www.blauer-engel.de/en

tablets and smartphones play an important role whereas the energy consumption during the use phase is rather negligible compared to other ICT products (if focussing only on the products themselves and not allocating the associated share of the underlying network system), pure energy labels like Energy Star are not included in this context.

The following Table 7-1 provides an overview of ecolabels relevant for tablet computers and smartphones. It can be seen that nearly all ecolabels besides Blue Angel include requirements for tablets in their criteria documents on computers, whereas TCO has developed a specific criteria document for tablet computers. On the other hand, only TCO and Blue Angel have developed criteria documents for mobile phones / smartphones, with only one certified product so far.

Table 7-1: Ecolabels relevant for tablet computers and smartphones

	EPEAT	TCO	EU Ecolabel	Nordic Swan	Blue Angel
Tablet computers	Yes; covered by criteria for “PC & displays”; 867 certified tablets/slates (476 gold, 391 silver)	2015; own criteria “TCO Certified tablets”; no certified products	Upcoming in 2016; covered by criteria for “Stationary and portable computers”	2013; covered by criteria for “Computers”	(excluded from the scope of “Computers”)
Mobile phones / Smartphones	---	2015; one certified product	---	---	2013; no certified products

Source: Oeko-Institut e.V.

Besides awarding products with eco labels, which for some product groups is rather seldom if the criteria are particularly challenging, ecolabel criteria often have further impacts; they serve for example as guidance for developing Green Public Procurement criteria; they are innovative in developing (new) top-runner criteria in terms of sustainability and they provide solutions with regard to measurement and verification of sustainability issues.

Referring to the most relevant sustainability issues of tablets and smartphones pictured in this report, such as raw materials extraction, socially responsible manufacturing, prolongation of product lifetime, as well as end-of-life management, the most relevant and best-practice ecolabel criteria of TCO for tablets and smartphones (TCO Development 2015a; 2015b), EU Ecolabel for computers (EU Commission 2015a), and Blue Angel for mobile phones (RAL gGmbH 2013) are exemplified more detailed in the Appendix (cf. Chapter 10).

8. Summary & recommendations

Smartphones and tablets are truly globalised products: with total annual sales numbers in excess of one billion devices, they are used in all parts of the world and by a broad range of income groups. The raw materials production and manufacturing also follow a global pattern: the cobalt for the batteries and the tantalum for capacitors are sourced from the DR Congo, among other places. The palladium for electronic components mainly comes from the Russian city of Norilsk and from South Africa; and the silver needed for soldering alloys comes from mines on all continents. The manufacturing of technologically demanding components such as processors, memory-chips and LCD-panels is dominated by industries in Korea, Taiwan, China and Japan. Less demanding parts such as capacitors and inductors are also manufactured in Thailand and Malaysia. The assembly of devices is done in countries like Brazil, China, India and Korea. This global travel often continues after the first use of smartphones and tablets: as demand for affordable IT-devices is high in many developing countries, these devices are often shipped to such regions to start a second product life or to be used as a source of spare parts.

Within these globalised patterns, smartphones and tablets are interlinked with a variety of sustainability issues, which can be summarised briefly as follows:

- The extraction of raw materials is often associated with human rights risks. The most prominent example is the extraction of raw materials in the eastern parts of the DR Congo where various armed groups use the local artisanal mining for tin, tantalum, tungsten and gold to finance their operations. In addition, other raw material supply chains of the EEE industry are also prone to human rights violations. This includes the sourcing of cobalt from south-eastern parts of the DR Congo and the violent labour disputes in South African platinum and palladium mines. Although mining and processing of ores are not always the dominant factors in these social hot spots, consumers and producers should be aware that the supply-chains of smartphones and tablets can be interlinked with these situations.
- Mining and processing of ores in many regions of the world are a major source of pollution and environmental degradation. Due to the large volumes of smartphones and tablets that are sold, this sector is a major consumer of materials such as cobalt, palladium, tantalum, silver, gold, indium and magnesium. Mining and processing of these materials and other minerals can lead to massive local pollution severely affecting human and environmental health.
- The production of smartphones and tablets is highly energy-intensive – particularly the production of display modules, printed circuit boards and integrated circuits. It is estimated that the life-cycle based greenhouse gas emissions of one smartphone account for 16 to 110 kg CO_2e, while the range for tablets is between 120 and 240 kg CO_2e, based on a number of studies. These broad ranges, however, are not necessarily the result of “better” or “worse” models, but are due to methodological differences between the LCA studies (e.g. the selection of certain datasets and databases and other methodological considerations for carrying out the LCA). For both product types, manufacturing is the major life-cycle step in terms of energy input and greenhouse gas emissions; other life-cycle steps such as transport, product-use and end-of-life management are comparatively less relevant.
- It becomes obvious that a major opportunity to reduce the total environmental and social impacts caused during raw materials extraction and manufacturing of smartphones and tablets is to use the devices as long as possible. Nevertheless, it is observed that smartphones and tablets are often used for no longer than 3 years. In many cases, the reason for early replacement of smartphones and tablets is not attributed to a defect. A large number of these products are replaced even though they are still functional (psychological obsolescence). The influence of

short innovation cycles, as well as advertising and the tariff models of service providers seem to play a decisive role in this regard.

- End-of-life management of smartphones and tablets is still far from perfect. Although mandatory legislative instruments such as the RoHS Directives in the EU, China, Korea and California widely ban the use of relevant hazardous substances in EEE, imperfect collection and processing causes significant losses of raw materials globally. In addition, recycling practices in many developing countries and emerging economies lead to significant pollution, e.g. from crude recycling practices such as the open burning of cables to recover copper. These problems are also aggravated by exports of used and end-of-life devices from industrialised to developing countries such as Ghana.

On the level of individual devices, many of the indicated impacts are quite moderate if compared to other aspects of our daily consumption: while the average annual life-cycle based impact of a smartphone leads to about 37 kg CO_2e emissions and that of a tablet to around 80 kg CO_2e[33] (note however that this does not include network usage as well as data centre services, for example for online storage or video streaming!), the average annual life-cycle based greenhouse gas emissions of a washing machine or a TV are associated with around 150 kg and 307 kg CO_2e respectively. In addition, in terms of total material consumption, it should be considered that devices such as TVs and cars obviously consume more non-renewable resources than smart-phones and tablets.

Nevertheless, these comparisons should not be taken as an excuse to continue with business as usual and to declare the problems outlined in this report as irrelevant. In sum, impacts are significant because of the large size of the global smartphone and tablet market. Various voluntary and mandatory approaches such as on-the-ground projects to improve conditions in artisanal mining, the restrictions of hazardous substances (RoHS), regulations on sound-end-of-life management and efficiency gains through improved manufacturing technologies have already led to significant improvements in the last decade. Consumers, industry and policy-makers are called on to continue on this path and strive for more sustainable life-cycles of electronic gadgets.

From the current perspective, the most relevant potential measures to further improve the overall impacts of smartphones and tablets are:

Increasing efforts in the field of sustainable mining: The electronics industry should mainly focus its effort on the supply-chains of those materials where electronic devices have a pro-nounced share of total world consumption (e.g. cobalt, silver and others). Generally, these efforts should go beyond de-facto boycotts to avoid unsustainable production and extend into industry partnerships to increase the share of sustainably mined raw materials globally.

Conducting human rights due diligence: The mining and processing of ores, but also the labour intensive assembly stages are known to be associated with various human rights risks such as conflict financing and violations of ILO core conventions. Producers should continue to address these problems, in particular through implementing comprehensive human rights due diligence policies and measures. This fits into the framework of the UN Guiding Principles on Business and Human Rights, which explicitly call on businesses to protect and respect human rights, and to remedy human rights violations within their business sphere.

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[33] Annual life-cycle based greenhouse gas emissions are calculated with following assumptions: (1) Life-time – smartphones 3 years, tablet-PC 3 years, television 6 years and washing machine 10 years; (2) Total life-cycle based greenhouse gas emissions: Smartphones 110 kg CO_2e, tablet-PC 240 kg CO_2e, television 1839 kg CO_2e and washing machine 1503 kg CO_2e.

Continuous improvement to reduce energy-input and chemical use in manufacturing: A handful of components, such as memory (RAM), printed circuit boards and displays cause almost 80% of the total greenhouse gas emissions of manufacturing. While the supply chain of smartphones and tablets is very complex, concentrating on improving the environmental performance of the suppliers of above mentioned components seems to be an appropriate approach. Designing energy efficient clean room technologies, using compressed air efficiently, implementing energy efficient soldering as well as cooling technologies, minimising PFC-emissions and substituting and optimizing the use of VOC-based solvents are a few innovative approaches which can be enforced in the supply chain base. The key would be to install monitoring systems with suppliers to closely monitor savings on energy consumption and greenhouse gas emissions.

Conducting and publishing robust and transparent LCAs: The robustness and value of publicly communicated LCA results depends on the use of a standard LCA methodology and making underlying assumptions, decisions and data use transparent. These aspects are crucial indicators for the quality of any LCA project. Thus, it is recommended that companies conduct LCA according to the full requirements of ISO 14044 including requirements for conducting critical reviews, taking into account additionally agreed sector specific rules, and providing as much transparency as possible for interpretation of results. The European Commission initiative, which builds on ISO 14040 and 14044 and aims to define all decision points to maximise comparability and robustness of results, is noteworthy. The initiative and legislative process is not yet completed but could potentially provide a stimulus to more widespread availability of high quality LCA data. In the meantime, companies are advised to conduct LCAs for major products that contribute substantially to their overall sales volume as well as at major product development phases, such as during design of a new product or to support decisions related to material and supplier selection.

Further reducing the types and amounts of hazardous substances: Although various legislative efforts worldwide have led to a significant reduction of hazardous substances in electronic devices, devices like smartphones and tablets are still not free from such chemicals. Thus, additional efforts are needed that go beyond the current legislative requirements. Amongst others, this could include the global application of the chemicals assessment applied under REACH and a support of initiatives such as the Zero Discharge of Hazardous Chemicals by electronics manufacturers. Last but not least, efforts to phase out hazardous chemicals in EEE should be continued beyond the existing RoHS-frameworks.

Promoting longer product use by changing product design and business models: Extension of product life-time is a decisive strategy to improve resource efficiency and the associated environmental and social impacts of manufacturing in the ICT sector. One of the main leverage points to increase the time products are used are the business models offered by the service providers. Rather than sending brand new models of smartphones when contracts are extended or renewed every 12 or 24 months, a more sustainable approach would be to set incentives to continue using the existing models. Simultaneously, service providers and manufacturers could complement the replacement of older models by implementing take-back mechanisms, guaranteeing safe data wiping and data transfer onto the new model and refurbishment, upgrade and resale for further use. From the perspective of product design, it is important that at least those components that are critical for limiting the usage time of smartphones and tablets are replaceable and upgradeable. These components are batteries, display, memory and storage. On the other hand, it is important that increased modularity of smartphones and tablets does not result in the opposite effect and lead to higher failure susceptibility. Thus, it is important that modular products –

as well as other devices – undergo comprehensive durability tests, also under extreme use conditions, to ensure lower failure rates.

Further opportunities for design changes are standardised charging interfaces. Standardised chargers are not only convenient for consumers, but can also help to reduce the production volumes of new chargers, which are generally delivered with every new smartphone / tablet purchased. Although the standards and technologies for such design changes already exist, they have not yet been implemented on a broad scale.

Product design facilitating sound recycling: This is particularly relevant for the batteries containing cobalt, which have to be separated from devices for sound recycling. Rechargeable batteries in smartphones and tablets are one of the most important applications of cobalt, which is at least partly mined under quite dubious conditions in the DR Congo. As most recycling processes depend on quick and efficient processes, ideal design should facilitate battery removal without the use of tools and within a few seconds of manual labour input. Generally, it should be ensured that such design changes do not negatively affect product durability.

Facilitating re-use and recycling by improving collection systems for end-of-life devices: This means in particular that small electronic devices such as smartphones and tablets are collected separately from other waste and e-waste types such as household equipment. Collection needs to be organised in a way that provides sound and convenient disposal options for consumers. In addition, collected devices need to be stored and transported in a way that minimises damage to the equipment to facilitate possibilities for the re-use of devices. Finally, the separate collection of smartphones / tablets promotes possibilities for improved dismantling, e.g. removal of batteries.

Improving the overall recycling of smartphones and tablets: The recycling process for smartphones and tablets can be improved in many regions of the world. While in many industrialised countries improved dismantling can contribute to improved material recovery, most developing countries and emerging economies still lack capacity for environmentally sound recycling. While there needs to be a concerted global effort to address this situation, at the same time illegal waste shipments have to be reduced as far as possible. To strengthen recycling systems in developing countries and emerging economies, strategies should not be limited to the transfer of recycling technology, but should promote financing mechanisms that allow sound recyclers to be economically competitive against recycling industries that externalise costs onto society.

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10. Appendix: Ecolabel criteria

The following sections provide the most relevant and best-practice ecolabel criteria referring to the most relevant sustainability issues of tablets and smartphones pictured in this report, such as raw materials extraction, social responsible manufacturing, prolongation of product lifetime, as well as end-of-life management by TCO for tablets and smartphones (TCO Development 2015a, 2015b), the EU Ecolabel for computers (EU Commission 2015a), and the Blue Angel for mobile phones (RAL gGmbH 2013).

10.1. Ecolabel criteria on responsible sourcing of raw materials

- The Brand owner shall have a public conflict minerals policy and also indicate all the initiatives they are using/funding. It is TCO Developments opinion that the OECD Due Diligence Guidance for Responsible Supply Chain of Conflict-Affected or High-risk Areas is the most ambitious approach in the list. At least one of the following options shall be marked: A Due Diligence process based on the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected or High-risk Areas; iTSCi (International Tin Research Institute (ITRI) Tin Supply Chain Initiative); CFTI (Conflict-free Tin Initiative); PPA (The Public-Private Alliance for Responsible Minerals Trade); Other relevant DRC in-region initiative; CFSI (EICC/GeSi Conflict-Free Sourcing Initiative). (TCO Tablets / Smartphones)
- The applicant shall support the responsible sourcing of tin, tantalum, tungsten and their ores and gold from conflict-affected and high-risk areas by conducting due diligence in line with the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas, and promoting responsible mineral production and trade within conflict-affected and high-risk areas for the identified minerals as used in components of the product and in accordance with OECD guidance. The applicant shall provide a declaration of compliance with these requirements together with the following supporting information: A report describing their due diligence activities along the supply chain for the four minerals identified. Supporting documents such as certifications of conformity issued by the European Union's scheme shall also be accepted; and identification of component(s) which contain the identified minerals, and their supplier(s), as well as the supply chain system or project used for responsible sourcing. (EU Ecolabel Computers)

10.2. Ecolabel criteria on socially responsible manufacturing

10.2.1. Blue Angel

- Fundamental principles and rights with respect to the universal human rights, as specified in the applicable core labour standards of the International Labour Organisation (ILO Core Labour Standards) shall be complied with during manufacture (assembly) of the Blue Angel eco-labelled products. (Blue Angel Mobile phones)

10.2.2. TCO

- Commitment: The Brand owner shall have a code of conduct that is considered consistent with the following in the manufacturing of TCO Certified products (TCO Tablets / Smartphones):
  - ILO eight core conventions: 29, 87*, 98*, 100, 105, 111, 138 and 182. *In situations with legal restrictions on the right to freedom of association and collective bargaining, nonmanagement

workers must be permitted to freely elect their own worker representative(s) (ILO Convention 135 and Recommendation 143).

– UN Convention on the Rights of the Child, Article 32.

– Relevant local and national Health & Safety and Labour laws effective in the country of manufacture.

- Structured work: The Brand owner shall ensure that routines are in place to implement and monitor their code of conduct in the manufacturing of TCO Certified products. In the final assembly factories the Brand owner shall ensure the implementation of their code of conduct through factory audits. In the final assembly factories and in the rest of the supply chain the Brand owner shall ensure that a corrective action plan is developed and fulfilled within reasonable time for all violations against their code of conduct that the Brand owner is made aware of. (TCO tablets / smartphones)
- Proof: TCO Development may conduct/commission random factory inspections (spot-checks) at any final assembly factory manufacturing TCO Certified products for the Brand owner and may require full audit reports during the certification period in order to assess social commitment and advancement. TCO Development may also require seeing corrective action plans and auditing reports from factories further down the supply chain to ensure that corrective actions have been successfully implemented. TCO Development additionally requires the documentation below to be verified by a third party approved verifier. (TCO tablets / smartphones)

10.2.3. EU Ecolabel

- Having regard to the International Labour Organisation's (ILO) Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy, the UN Global Compact (Pillar 2), the UN Guiding Principles on Business and Human Rights and the OECD Guidelines for Multi-National Enterprises, the applicant shall obtain third party verification supported by site audits that the applicable principles included in the ILO fundamental conventions and the supplementary provisions identified below have been respected at the final assembly plant for the product. Fundamental conventions of the ILO:

  – Child Labour:
    - Minimum Age Convention, 1973 (No. 138)
    - Worst Forms of Child Labour Convention, 1999 (No. 182)

  – Forced and Compulsory Labour:
    - Forced Labour Convention, 1930 (No. 29) and 2014 Protocol to the Forced labour Convention
    - Abolition of Forced Labour Convention, 1957 (No. 105)

  – Freedom of Association and Right to Collective Bargaining:
    - Freedom of Association and Protection of the Right to Organise Convention, 1948 (No. 87)
    - Right to Organise and Collective Bargaining Convention, 1949 (No. 98)

      In locations where the right to freedom of association and collective bargaining are restricted under law, the company shall recognise legitimate employee associations with whom it can enter into dialogue about workplace issues.

- Discrimination:
  - Equal Remuneration Convention, 1951 (No. 100)
  - Discrimination (Employment and Occupation) Convention, 1958 (No. 111)
- Supplementary provisions:
  - Working Hours: ILO Hours of Work (Industry) Convention, 1919 (No. 1)
  - Remuneration: ILO Minimum Wage Fixing Convention, 1970 (No. 131); Living wage: The applicant shall ensure that wages paid for a normal work week shall always meet at least legal or industry minimum standards, are sufficient to meet the basic needs of personnel and provide some discretionary income. Implementation shall be audited with reference to the SA8000 guidance on "Remuneration";
  - Health & Safety: ILO Occupational Safety and Health Convention, 1981 (No.155); ILO Safety in the use of chemicals at work Convention, 1990 (No.170)

- The audit process shall include consultation with external stakeholders in local areas around production sites, including trade unions, community organisations, NGOs and labour experts. The applicant shall publish aggregated results and key findings from the audits online in order to provide evidence of their supplier's performance to interested consumers.
- Assessment and verification: The applicant shall show compliance with these requirements by providing copies of certificates of compliance and supporting audit reports for each final product assembly plant for the model(s) to be eco labelled, together with a web link to where online publication of the results and findings can be found. Third party site audits shall be carried out by auditors qualified to assess the compliance of the electronics industry supply chain with social standards or codes of conduct or, in countries where ILO Labour Inspection Convention, 1947 (No 81) has been ratified and ILO supervision indicates that the national labour inspection system is effective and the scope of the inspection system covers the areas listed above, by labour inspector(s) appointed by a public authority. Valid certifications not older than 12 months prior to the application and that are provided by schemes or processes that, together or in part, audit compliance with the applicable principles of the listed fundamental ILO Conventions and the supplementary provisions on working hours, remuneration and health & safety, shall be accepted.

10.3. Ecolabel criteria on prolonging product lifetime

10.3.1. Design for Durability

- Durability tests: The tablet computer model shall pass durability tests with regard to accidential drop and screen resilience. (EU Ecolabel Computers)
- Minimum battery life:
  - Tablets shall provide the user with a minimum of 7 hours of rechargeable battery life after the first full charge. Tablet rechargeable batteries shall meet the following performance requirements, which are dependent on whether the rechargeable battery can be changed without tools: Models in which rechargeable batteries can be changed without tools shall maintain 80% of their declared minimum initial capacity after 750 charging cycles; models in which rechargeable batteries cannot be changed without tools shall maintain 80% of their declared minimum initial capacity after 1000 charging cycles. The applicant shall provide a minimum two year commercial guarantee for defective batteries. Information about known factors

influencing the lifetime of rechargeable batteries, as well as instructions on how the user can prolong battery life, shall be included in factory installed energy management software, written user instructions and posted on the manufacturer's website. (EU Ecolabel Computers)

– Specified life and life cycle test for batteries of mobile phones with defined Test Specifications for Rechargeable Lithium Batteries (Blue Angel Mobile phones)

- Charging Interface: The mobile phone shall be rechargeable by means of a standardized charger complying with the EN 62684 standard "Interoperability specifications of common external power supply (EPS) for use with data-enabled mobile telephones" and equipped with a correspondingly defined USB interface. (Blue Angel Mobil phones)
- Software Updates: The devices shall have a function to keep the operating system up-to-date free of charge. The updates shall, above all, close security gaps and provide other software updates, if any. (Blue Angel Mobil phones)
- Data Deletion: To allow a second use of a mobile phone the device shall be designed so as to allow the user to completely and safely delete all personal data on his own without the help of pay software. This can be achieved by either physically removing the memory card or with the help of software provided by the manufacturer free of charge. When using software, the deletion process shall at least include an overwriting of all the data stored with a random pattern. (Blue Angel Mobil phones)

10.3.2. Design for upgrades and repair

- The following components of computers shall be easily accessible and exchangeable by the use of universal tools (i.e. widely used commercially available tools such as a screwdriver, spatula, plier, or tweezers): Data storage (HDD, SSD or eMMC), Memory (RAM), Screen assembly and LCD backlight units (where integrated). The rechargeable battery pack shall be easy to extract by one person (either a non-professional user or a professional repair service provider). (EU Ecolabel Computers)
- Rechargeable batteries shall not be glued or soldered into a product and there shall be no metal tapes, adhesive strips or cables that prevent access in order to extract the battery. In addition, the following requirements and definitions of the ease of extraction shall apply: For tablets it shall be possible to extract the rechargeable battery in a maximum of four steps using a screwdriver and spudger. Simple instructions on how the rechargeable battery packs are to be removed shall be provided in a repair manual or via the manufacturer's website. (EU Ecolabel Computers)
- Repair manual: The applicant shall provide clear disassembly and repair instructions (e.g. hard or electronic copy, video) to enable a non-destructive disassembly of products for the purpose of replacing key components or parts for upgrades or repairs. This shall be made publicly available or by entering the product's unique serial number on a webpage. Additionally, for portable computers a diagram showing the location of the battery, data storage drives and memory shall be made available in pre-installed user instructions and via the manufacturer's website for a period of at least five years. (EU Ecolabel Computers)

10.3.3. Warranty / guarantee

- The brand owner shall provide a product warranty for at least one year on all markets where the product is sold. (TCO Tablets / Smartphones)
- The applicant undertakes to offer a free minimum 2-year warranty on the mobile phone, except for the rechargeable battery. (Blue Angel Mobil phones)

- Commercial Guarantee: The applicant shall provide at no additional cost a minimum of a three year guarantee effective from purchase of the product. This guarantee shall include a service agreement with a pick-up and return or on-site repair option for the consumer. This guarantee shall be provided without prejudice to the legal obligations of the manufacturer and seller under national law. (EU Ecolabel Computers)

10.3.4. Availability of spare parts

- The brand owner shall guarantee the availability of spare parts for at least three years from the time that production ceases. Instructions on how to replace these parts shall be available to professionals upon request. (TCO Tablets / Smartphones)
- Availability of spare parts: The applicant shall ensure that original or backwardly compatible spare parts, including rechargeable batteries (if applicable), are publicly available for at least five years following the end of production for the model. (EU Ecolabel Computers)

10.4. Ecolabel criteria on end of Life management

10.4.1. Take back schemes

- The brand owner (or its representative, associated company or affiliate) shall offer their customers the option to return used products for environmentally acceptable recycling methods in at least one market where the product is sold and where electronics take back regulation is not in practice at the date of application. (TCO Tablets / Smartphones)
- The applicant shall operate its own take-back scheme for mobile phones to direct all collected devices to proper treatment (reuse, recovery and/or recycling). The applicant shall actively communicate this system to its customers. This take-back scheme can be based on collections at the branches, return campaigns, deposit systems or the like. A mere reference to the collection governed by the Elektro- and Elektronikgesetz (ElektroG) (Electrical and Electronic Equipment Act) would not be sufficient. The collection system can be organised by the applicant itself, by contracting partners and/or together with other manufacturers of mobile phones. (Blue Angel Mobile phones)

10.4.2. Design for recycling

- The rechargeable batteries shall be easy to remove for recycling purposes to allow their recycling by material type separate from the rest of the device. An efficient removal of the rechargeable batteries for recycling purposes shall be possible by using standard tools (guidance value: in no more than 5 seconds). The housing of the device may be damaged during this process but the leaking of battery chemicals must be prevented. (Blue Angel Mobile phones)
- For recycling purposes computers shall be designed so that target components and parts can be easily extracted from the product. A disassembly test shall be carried out according to a specified test procedure. The test shall record the number of steps required and the associated tools and actions required to extract the target components and parts. The following target components and parts, as applicable to tablet computers, shall be extracted during the disassembly test: Printed Circuit Boards >10 cm^2 relating to computing functions; Rechargeable battery. Displays (where integrated into the product enclosure): Printed Circuit Boards >10 cm^2, Thin Film Transistor unit and film conductors in display units >100 cm^2 and LED backlight units.

At least two of the following target components and parts, selected as applicable to the product, shall also be extracted during the test: HDD drive (portable products), optical drives (where included), printed circuit boards ≤ 10 cm^2 and > 5 cm^2. The applicant shall provide a 'disassembly test report' to the competent body detailing the adopted disassembly sequence, including a detailed description of the specific steps and procedures, for the target parts and components listed above. The disassembly test may be carried out by the applicant, or a nominated supplier, in their own laboratory, or an independent third party testing body, or a recycling firm that is a permitted electrical waste treatment operation in accordance with Article 23 of Directive 2008/98/EC. (EU Ecolabel Computers)