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Evaluation of international mobile phone collection systems including a case study of the charitable campaign “Ö3-Wundertüte”

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approx.	approximately
AU$	Australian dollar
cap	capita
ICT	information and communications technology
inh.	inhabitants
IT	information technology
kg	kilogram
NGO	non-governmental organisation
NZ$	New Zealand dollar
t	tonne
US$	United States dollar
WEEE	waste electrical and electronic equipment

Abstract

Mobile phones are among the most widely used types of electrical equipment across the planet. Given their relatively short service life, considerable amounts of end-of-life mobile phones are generated annually, which contain both valuable and hazardous materials. Furthermore, mobile phones frequently are still functional after the first use. In many cases, however, end users chose to store their old devices at home. These unused amounts represent an important stock of resources, which require to be recovered for reuse and recycling. In this thesis, the situation of mobile phone collection in Austria is analysed, which includes an estimation of the waste potential of this specific waste stream using the time step method as well as a case study about the country's most widespread charitable collection campaign "Ö3-Wundertüte". Furthermore, 27 well-established collection systems from 15 different countries are analysed and compared in order to determine the factors that contribute to high collection quantities.

The results show that between 2004 and 2014 approx. 2.7 million mobile phones become obsolete in Austria annually, of which roughly 1.4 million are stockpiled in households every year. 550,000 units are donated, disposed of at municipal WEEE collection points or taken back by providers and, therefore, represent a separately collected waste stream. Related to the quantities put on the Austrian market, this results in a collection rate of only 17 %. An analysis of in-depth collection data of the "Ö3-Wundertüte" campaign indicates that the average lifespan of mobile phones collected between 2011 and 2015 is 7.2 years. While an increasing share of more modern smartphones is donated to the programme, older models with release years prior to the mid-2000s still represent the majority of the collected items. Finally, by evaluating well-established systems on an international level, it can be concluded that convenience to the end user by setting up a dense network of public drop-off points and providing free-post envelopes as well as creating widespread public awareness about the programme are essential factors of success. The highest results are achieved by the Swiss WEEE collection system "Swico" with an average of 68 units per 1,000 inhabitants. The Austrian "Ö3-Wundertüte" collects approx. 47 units per 1,000 inhabitants and can, therefore, be regarded as the most successful among the systems that specifically focus on mobile phones.

Zusammenfassung

Mobiltelefone zählen zu den weltweit meist verwendeten Elektrogeräten. Angesichts ihrer relativ kurzen Nutzungsdauer fallen pro Jahr substantielle Mengen gebrauchter Geräte an, welche sowohl Wertstoffe wie auch gefährliche Materialien enthalten. Nach ihrer Erstnutzung sind Mobiltelefone außerdem in vielen Fällen noch funktionsfähig, jedoch verbleiben sie häufig in den Haushalten ihrer LetztnutzerInnen. Diese Mengen stellen somit einen bedeutenden Bestand an ungenutzten Ressourcen dar, dessen Erfassung zur stofflichen Verwertung und Wiederverwendung im Sinne einer erhöhten Ressourceneffizienz erforderlich ist. Diese Arbeit beschreibt im ersten Teil die gegenwärtige Situation der Mobiltelefonsammlung in Österreich basierend auf einer Abschätzung des Abfallpotentials dieses Gerätetyps mittels der Time-Step-Methode. Außerdem wird die landesweit größte karitative Sammelaktion, die „Ö3-Wundertüte“, im Rahmen einer Fallstudie analysiert. Der zweite Teil enthält einen Vergleich von 27 Sammelsystemen für Mobiltelefone aus 15 Ländern, um jene Faktoren herauszuarbeiten, die für hohe Sammelmengen essentiell sind.

Die Ergebnisse zeigen, dass in Österreich zwischen 2004 und 2014 im Durchschnitt rund 2,7 Millionen Mobiltelefone pro Jahr aus der Erstnutzung gefallen sind, von denen 1,4 Millionen zunächst in den Haushalten aufbewahrt wurden. 550.000 Stück wurden gespendet, bei Sammelstellen der Gemeinden entsorgt oder von Mobilfunkdienstleistern zurückgenommen und stellen somit einen getrennt erfassten Abfallstrom dar. Bezogen auf die in Österreich in Verkehr gebrachte Menge ergibt dies eine Sammelquote von nur 17 %. Die Auswertung von detaillierten Sammeldaten der „Ö3-Wundertüte“ zeigt eine durchschnittliche Lebensdauer der zwischen 2011 und 2015 erfassten Geräte von 7,2 Jahren. Obwohl ein zunehmender Anteil an modernen Smartphones gespendet wird, stellen ältere Modelle, welche typischerweise zu Beginn der 2000er Jahre auf den Markt gebracht wurden, noch immer den Großteil der Sammelmengen dar. Der Vergleich von gut etablierten Sammelsystemen auf internationaler Ebene zeigt, dass leichte Zugänglichkeit durch portofreie Rücknahmekuverts und ein dichtes Netzwerk an Abgabestellen sowie die Schaffung eines hohen Bekanntheitsgrades entscheidende Faktoren für hohe Sammelergebnisse sind. Mit durchschnittlich 68 Stück pro 1.000 Einwohnern erreicht das Schweizer Sammelsystem für Elektroaltgeräte „Swico“ das beste Ergebnis gefolgt von der „Ö3-Wundertüte“ mit 47 Stück pro 1‘000 Einwohnern. Unter jenen Systemen mit ausschließlichem Fokus auf Mobiltelefone kann die „Ö3-Wundertüte“ somit als das erfolgreichste betrachtet werden.

1. Introduction

E-waste or waste electrical and electronic equipment (WEEE) is considered one of the fastest growing waste streams worldwide (CUCCHIELLA et al., 2015; PERKINS et al., 2014). BALDÉ et al. (2015) estimate that global e-waste quantities will increase by almost 20 % from 41.8 t in 2014 to 50 t in 2018. Mobile phones, which belong to the category of small IT equipment, are characterised by a particularly steep rise in the numbers of users (WILHELM et al., 2015). According to the International Telecommunication Union (ITU, 2017), the number of mobile-cellular telephone subscriptions, which corresponds to the amount of mobile phones in use, has increased by a factor of eight from 2001 to 2017. In the 2000s, this trend developed at an almost exponential rate. For the year 2017, the estimated global average number of mobile-cellular subscriptions is more than 7.7 billion or roughly 104 per 100 inhabitants. In developed countries this share is currently approx. 127, while developing nations have reached almost 99 subscriptions per 100 citizens (ITU, 2017). These figures indicate that the mobile phone has become an indispensable piece of equipment in many people's lives across the planet. In only four decades, mobile phones have evolved from rather large and bulky devices, which could weigh up to four kg (MPPI, 2012), to small and affordable multifunctional computers, which are widely used among all classes of society (BABAYEMI et al., 2017). Unlike other types of electrical and electronic equipment and especially in high-income countries, mobile phones are frequently regarded as "up-to-date products" (COX et al., 2013), which are important for people's individual and social identities. Therefore, these devices are likely to be disposed of because of fashion trends, aesthetic appeal or product innovations rather than technical failure (COX et al., 2013). Also PRAKASH et al. (2016) conclude that psychological obsolescence and the desire for a new device are particularly relevant for limiting the service life of mobile phones. Therefore, mobile phones are characterised by a relatively short duration of use of approx. two to three years (WIESER & TRÖGER, 2015; ANDARANI & GOTO, 2014; JANG & KIM, 2010; MURAKAMI et al., 2009) and are frequently still functional at the end of use (SPEAKE & NCHAWA YANGKE, 2015). As a consequence, some end users sell their used devices or trade them in at mobile network providers, which led to the establishment of significant second-hand markets (GEYER & DOCTORI BLASS, 2010). Collecting used handsets for refurbishment and resale has, therefore, been identified as a commercial activity and an opportunity to raise funds for charitable purposes (ONGONDO & WILLIAMS, 2011a).

Apart from the economic motivation, also the devices' material content justifies their collection and end-of-life treatment. From a resource point of view, mass-relevant materials are plastics, glass, copper, aluminium and ferrous metals. Depending on the battery type, additional elements are nickel and potassium in the case of nickel-cadmium and nickel-metal hydride batteries, which may still be found in older models, and cobalt contained in lithium-ion batteries (MPPI, 2009a). According to the Swiss WEEE collection system "Swico" (SENS/SWICO/SLRS, 2017), plastic components account for more than one third of the device's weight. As can be seen further from Figure 1, around 23 % constitute printed circuit boards (PCB), which contain base elements such as ceramics, copper, tin and zinc and the majority of precious metals such as gold, silver, palladium and platinum (MPPI, 2009a; CUCCHIELLA et al., 2015).

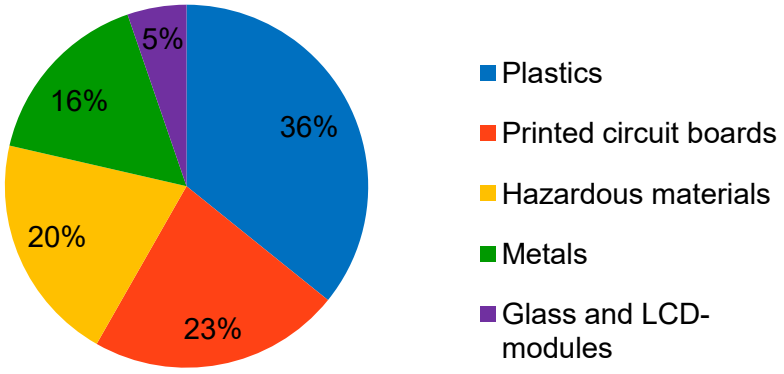

Figure 1. Composition of mobile phones collected in Switzerland in 2016 (based on SENS/SWICO/SLRS, 2017)

Overall, mobile phones may contain up to 40 different elements (HAGELÜKEN & MESKERS, 2008). As can be seen from Table 1, the content of precious metals is relatively low. Nevertheless, these elements determine the vast majority of the devices' material value. CUCCHIELLA et al. (2015) estimate that the gold content of smartphones contributes to 56 % of the recycling revenue, while 15 % are attributed to palladium, 7 % to platinum and cobalt, 5 % to silver and 3 % to copper and plastics. Assuming a gold content of 0.035 g/unit (MPPI, 2009a) and an average gold price of US$ 1,249 per troy ounce or US$ 40.16 per g in 2016 (WORLD BANK, 2017a), one mobile phone would have a theoretical material value of US$ 1.40 just because of the amount of gold used. Hence, mobile phones constitute an important source of valuable materials (OGUCHI et al., 2011).

Table 1. Selected metals contained in mobile phones from various sources (g/unit)

Element	CUCCHIELLA et al. (2015)	CHRISTIAN et al. (2014)	GEYER & DOCTORI BLASS (2010)	MPPI (2009a)	HAGELÜKEN & MESKERS (2008)
Silver (Ag)	0.244 - 1	0.060 - 0.130	0.300 - 0.310	0.348	0.250
Gold (Au)	0.024 - 0.038	0.030 - 0.040	0.028 - 0.037	0.035	0.024
Palladium (Pd)	0.009 - 0.015	0.006	0.012 - 0.019	0.014	0.009
Copper (Cu)	14 - 26	10	8.840 - 14.850	10	9

Mobile phones also contain substances which can have detrimental effects on the environment and human health when treated in an improper manner. Beryllium, which is added to copper alloys, may be emitted as dust during the smelting process and can cause damages to the lung (MPPI, 2009a). Lead was frequently added to solders, but as its use is strictly limited by the European RoHS Directive (2011/65/EU), current models are produced with lead-free solders, but can still have low amounts between 0.1 and 0.01 g (CHRISTIAN et al., 2014). Hence, older devices found in the waste stream may contain higher levels of lead. The same applies for cadmium from nickel-cadmium batteries, which are nowadays replaced by lithium-ion batteries (MPPI, 2012). MARAGKOS et al. (2013) analysed the content of heavy metals in mobile phones and could determine the presence of cadmium and mercury, whose concentration levels, however, fell below the limits set by the RoHS Directive. The quantities of lead and chromium of several models released before 2006,

though, were found to exceed the provisions of the Directive (MARAGKOS et al., 2013). Other metals of potential concern are chromium from chrome-plated metal surfaces, antimony in solders and flame retardants and arsenic, which is used in several components such as integrated circuits (MPPI, 2009a). When mobile phones are landfilled, these substances may become soluble in contact with acids and leach out causing contamination of ground water and soils (MPPI, 2009a). Furthermore, informal recycling practices, which include manual dismantling and open burning, cause significant environmental pollution and health problems to the local population (KIDDEE et al., 2013). Open burning in backyards or on landfills releases, for instance, brominated flame retardants, which are precursor chemicals for brominated dioxins (BABAYEMI et al., 2017). Therefore, considering the content of both valuable resources and hazardous materials as well as the high quantities of devices produced and disposed of, end-of-life mobile phones need to be collected and treated in an environmentally sound manner.

To date, collection systems for mobile phones have been analysed for several countries. SILVEIRA & CHANG (2010) analyse 17 collection schemes in the USA and provide an overview of existing initiatives in Brazil. The authors stress the importance of second-hand markets for the financing of take-back schemes as well as the ability of several partners such as retailers and telecommunication providers to establish a widespread collection network. They propose a deposit or advance recycling fee scheme in order to implement the extended producer responsibility (EPR) concept in Brazil and to increase collection quantities (SILVEIRA & CHANG, 2010). Collection and recycling systems for mobile phones in South Korea are discussed by JANG & KIM (2010). Based on a consumer survey and an estimation of the waste potential, the authors conclude that a high share of end-of-life mobile phones is stored in households. They recommend a denser network of drop-off points and more collective efforts by the industry, retailers and local governments (JANG & KIM, 2010). PONCE-CUETO et al. (2011) identify and discuss several actors involved in the collection of end-of-life mobile phones in Spain and note a low recovery rate of this waste stream. This is ascribed to a lack of public awareness about how and where to dispose of the old device as well as to the fact that used mobile phones are frequently sold by the end user, which led to the emergence of significant second-hand markets. The authors advocate a regulation of these reuse channels in order to ensure environmentally sound treatment (PONCE-CUETO et al., 2011). ONGONDO & WILLIAMS (2011a) evaluate mobile phone take-back schemes in the UK according to collection method, target groups, advertisement, incentives and convenience of use. They conclude that these voluntary systems significantly contribute to diverting devices to recycling and reuse, however, due to data gaps on collection quantities it is not possible to determine which scheme performs best. PANAMBUNAN-FERSE & BREITER (2013) examine the life cycle of mobile phones and assess their current end-of-life management in the Indonesian city of Manado. As legislation on e-waste is lacking, obsolete devices frequently end up in landfills. The authors call for legal regulations concerning the take-back of end-of-life equipment, raising public awareness of mobile phone recycling and setting up an effective waste management infrastructure (PANAMBUNAN-FERSE & BREITER, 2013). BEIGL et al. (2012) choose an international approach and compare several well-established mobile phone collection systems from different countries. Based on an analysis of collection method, organisation, funding and treatment, the authors introduce a classification scheme comprising four different system types: WEEE collection system, branch system, commercial refurbishing and charitable

refurbishing. By comparing available collection quantities related to population size, they conclude that convenience and broad information for end users are essential factors for a system's success (BEIGL et al., 2012).

Being an important source of information for the end-of-life management, the waste potential of mobile phones has been estimated for several countries (Table 2). The results of several studies show that the quantities of end-of-life mobile phones generated increased over the last decades (LI et al., 2015; RAHMANI et al., 2014; POLÁK & DRÁPALOVÁ, 2012; ARAÚJO et al., 2012). GUO & YAN (2017), for example, calculated an average growth rate of more than 10 % in the last decade.

Table 2. Estimated end-of-life quantities of mobile phones for various countries

Reference	Country	Year	Quantity of obsolete mobile phones [million units]	Units per 1,000 inhabitants
GUO & YAN (2017)	China	2015	781.10	570
LI et al. (2015)	China	2012	739.98	548
GOLEV et al. (2016)	Australia	2014	12.00	511
RAHMANI et al. (2014)	Iran	2014	39.00	497
KIM et al. (2013)	South Korea	2010	17.02	343
POLÁK & DRÁPALOVÁ (2012)	Czech Republic	2010	1.50	143
		2008	1.30	125
ARAÚJO et al. (2012)	Brazil	2008	25.50	132
OSIBANJO & NNOROM (2008)	Nigeria	2007	7.00	48

In the first part, this thesis aims at providing an overview of how mobile phones are currently collected and treated in Austria. To date, no study estimating the amount of end-of-life mobile phones in Austria could be identified. In order to provide insights into the waste potential of this specific waste stream, the time step method is applied. Combined with a consumer survey by WIESER & TRÖGER (2015), the paths that these phones typically take after use are quantified. Following an evaluation of current collection programmes in Austria, the well-known and nationwide operating charitable system "Ö3-Wundertüte" is discussed as a case study. In-depth collection data provided by the programme is analysed in terms of the devices' lifespan and condition.

The second part is dedicated to an analysis of mobile phone collection systems from several different nations. For this section, only well-established and widespread schemes for which sufficient data was available are considered. This part aims at defining factors of success, i.e. factors that influence high collection quantities.

Finally, current trends and challenges for mobile phone collection systems are discussed and recommendations are formulated.

2. Methods

2.1 Calculation of waste potential of end-of-life mobile phones in Austria

In order to estimate the number of end-of-life electrical and electronic devices, various methods are available, among which input-output analysis is most frequently applied (WANG et al., 2013; LI et al., 2015). This approach is based on the assumption that future waste quantities depend on manufacturing volumes and product stock in use from past times (WALK, 2011). New products are introduced to society through sales (input flows), aggregate to a stock of devices in use and are eventually discarded by waste generators after a certain period of time, thereby leaving society as output flows (WANG et al., 2013; SALHOFER, 2001). Hence, vital information for estimating waste generation comprises sales figures, stock of equipment in use, lifespan data and disposal behaviour of consumers (CHANCEREL, 2010; CROWE et al., 2003). Several methods of input-output analysis have been developed, which are summarised in Table 3.

Table 3. Overview of calculation methods for WEEE generation (modified from CHANCEREL, 2010 and WANG et al., 2013)

Method	Required data				Market environment		Accuracy
	Sales	Stock	Lifespan distribution	Average lifespan	Saturated markets	Dynamic markets	
Time step	x	x			x	x	High
Market supply (simple delay)	x			x	x		Medium
Market supply (distribution delay)	x		x		x	x	High
Carnegie Mellon	x			x	x	x	High
Batch leaching (consumption and use)		x		x	x		Low
Sales	x				x		Low

As can be seen from Table 3, product lifespan data is essential information for estimating WEEE generation. Several methods either rely on a fixed mean lifetime value or assume a certain distribution such as normal or Weibull distribution (CHANCEREL, 2010; OGUCHI et al., 2010). However, as noted by CROWE et al. (2003), assuming a constant average value or distribution can be problematic in cases where changes in technology and consumer behaviour lead to decreasing or increasing lifespans. A case study at an U.S. university, for instance, showed that the mean lifetime of PCs decreased by more than five years from 1985 to 2000 (BABBITT et al., 2009). Hence, these methods are not suitable for dynamic markets,

which are characterised by growing demand in relation to population and continuous technological change rendering formerly up-to-date products obsolete (ARAÚJO et al., 2012). This is also the case for mobile phones, which rapidly evolved from rather simple handheld devices to sophisticated pocket-sized personal computers while accessing continuously advancing cellular networks. Consequently, the potential generation of end-of-life mobile phones in Austria is estimated by means of the time step method, which does not require product lifetime information and has been applied for the mobile phone case in other countries (LI et al., 2015; WANG et al., 2013; ARAÚJO et al., 2012; JANG and KIM, 2010). Requiring rather simple data input this method produces accurate estimations (LI et al., 2015; LIN, 2008) provided that stock and sales data are reliable (WANG et al., 2013).

The time step method is based on the principle that the difference between the amount of new products sold and the number of old products becoming obsolete results in changes in the total amount of devices being used in a society in a particular period (LIN, 2008). Consequently, the amount of WEEE generated in year n, W_n, is calculated by

$$W_n = POM_n - (S_n - S_{n-1}), \qquad \text{(Eq. 1)}$$

where POM_n is the amount of devices put on the market in year n, and S_n and S_{n-1} represent the stock of equipment in use in evaluation year n and the preceding year respectively (WANG et al., 2013).

Sales data is provided by market research company GfK for the years 2004 to 2014. The stock of equipment in use is derived from the number of mobile phone subscriptions, i.e. active SIM cards, published by ITU (2016). This figure represents subscriptions to a public mobile telephone service including post- and pre-paid SIM cards and excluding mobile broadband connections using USB modems (ITU, 2010). Therefore, it can be assumed that the number of subscriptions largely corresponds to the amount of mobile phones currently in use, although inaccuracies might be caused by dual SIM devices. In this case, two subscriptions might be linked to only one mobile phone. However, this impact is deemed negligible, which conforms to the approaches in CHANCEREL (2010), JANG and KIM (2010), ARAÚJO et al. (2012) and LI et al. (2015).

2.2 Database analysis of “Ö3-Wundertüte”

In this thesis, the charitable collection programme “Ö3-Wundertüte” is examined in detail with regard to quantities, condition and age of mobile phones as a case study. For this purpose, data on collected models provided by the processing entity “magdas Recycling”, which belongs to the social business company “magdas” founded by Caritas Vienna, was analysed.

The database excerpt comprises complete data on the total reuse quantity from 2011 to 2015, i.e. the amount of mobile phones that is processed and evaluated positively for reuse. These figures are differentiated according to brand and condition category. In addition, in-depth collection data on those most frequently tested models is given which account for 90 % of the total reuse quantity between 2011 and 2015. Per year, this results in 210 to 290 different mobile phone models, whose collection volume is subdivided into condition categories. Overall, data on 1,314,323 reusable and marketable mobile phones was available for analysis, which represents 60 % of the

total collection quantity (2,209,000) between 2011 and 2015. Defective or obsolete devices, which are sorted out for recycling, are not recorded in the database.

In order to calculate data on lifespan, each model's year of release was gathered from online databases gsmarena.com (ARENA COM, 2017) and phonearena.com (PHONEARENA, 2017) and, where available, cross-checked with manufacturers' press releases. In total, all analysed models were launched between 1998 and 2013. Age data was obtained by subtracting the year of release from the respective year of collection. For instance, a Nokia 3510i released in 2002 and collected in 2011 is assigned a lifetime of 9 years. This conforms to the definition of total lifespan by MURAKAMI et al. (2010), which is the length of time from production to treatment or recycling and, thus, not only comprises the duration of use and possibly reuse but also the storage span.

For comparison purposes with other works, parameters for the lifespan distribution were fitted to the data. Typically, lifetime data for WEEE is modelled by the Weibull distribution (GUO and YAN, 2017; MILLER et al., 2016; WANG et al. 2013; POLÁK and DRÁPALOVÁ 2012; WALK, 2009; TEMANORD, 2009), while the normal distribution is also proposed in the literature (CHANCEREL, 2010; CROWE et al., 2003). The cumulative distribution function $F(t)$ for the Weibull distribution is defined as

$$F(t) = 1 - e^{-(\frac{t}{\alpha})^{\beta}}, \qquad \text{(Eq. 2)}$$

where α is the scale parameter and β is the shape parameter (HEDDERICH and SACHS, 2016). In the context of electrical and electronic equipment, F(t) describes the share of discarded items at time t (TEMANORD, 2009). Hence, the proportion of products reaching their end-of-life in the period t_1 to t_2 is given as $F(t_2) - F(t_1)$ (WALK, 2009). The parameters of the Weibull distribution were calculated by maximum likelihood estimation, which was done in the statistical computing software R (R CORE TEAM, 2017) using function fitdistr from the package MASS as described in RICCI (2005). Several authors (WANG et al. 2013; WALK, 2009; TEMANORD, 2009) fitted distributions by minimising the sum of squared residuals, for example, by means of the Excel Solver. However, in this case graphical comparison showed that the maximum likelihood estimation produced a better fit to the data.

In addition, each model's weight and type, i.e. whether it is considered a smartphone or a feature phone, is retrieved from aforementioned websites and included in the dataset.

2.3 Analysis and comparison of mobile phones collection systems

The aim of this thesis is to provide insights into factors of success and current trends in the field of the end-of-life management of mobile phones. For this purpose, take-back systems for used mobile phones on an international level are reviewed and compared. In recent years, a myriad of schemes has been established. In 2009, the Mobile Phone Partnership Initiative (MPPI) exemplarily listed existing mobile phone recycling systems for 33 countries (MPPI, 2009b). SILVEIRA and CHANG (2010) discussed 22 major collection initiatives in the United States and Brazil, while ONGONDO & WILLIAMS (2011) could identify more than 100 voluntary schemes in the UK alone. Due to the vast number of international take-back programmes, this analysis focuses on well-established systems that are operating nationwide and for

which sufficient information is available. As collection systems differ according to organisation, objective, funding and treatment, the analysed schemes are classified according to BEIGL et al. (2012). Thus, four different types of collection systems exist: WEEE collection system, branch system, commercial refurbishing and charitable refurbishing (BEIGL et al., 2012). The selected take-back schemes are described and analysed based on criteria such as organisation, collection method, target groups, incentives, treatment and destination of collected devices, collection performance, promotion and advertising, and funding. Necessary information was obtained through literature review, document analysis and interviews per e-mail and in person. In order to facilitate comparison, available collection volumes are related to population size, which was retrieved from national statistical offices. The majority of take-back schemes reports collected quantities in units. As various sources (e.g. GUO & YAN, 2017; WANG et al., 2013; SENS/SWICO/SLRS, 2012-2017) indicate that the average weight of mobile phones varies considerably depending on the year of production, the collection performance is displayed in units as it is declared in the original data.

3. Collection of end-of-life mobile phones in Austria

In this chapter, an overview of the current end-of-life management of mobile phones in Austria is given. Based on an estimation of the potential quantity of this specific waste stream, several actors involved in the collection and treatment of used devices in Austria are presented and analysed. In a case study, the charitable campaign “Ö3-Wundertüte” is analysed in more detail concerning organisation and characteristics of collected quantities.

3.1 Quantities of end-of-life mobile phones in Austria

The results of the time step method for Austrian mobile phones from 2004 to 2014 are shown in Table 4 and Figure 2. On average, approx. 2.7 million devices become obsolete per year (Table 4). The sharp increase of end-of-life quantities in 2013 and 2014 is primarily caused by a decrease of mobile phone subscriptions due to data cleansing by network providers (RTR, 2015). Recent data suggests that the number of active SIM-cards remained relatively constant at 13,5 million in 2015 (RTR, 2016). In the case of minor annual changes in the stock of devices in use, the amount of obsolete devices will roughly equal the amount of mobile phone sales.

Table 4. Estimated number of end-of-life mobile phones in Austria from 2004 to 2014 using the time step method (units)

Year	Mobile phone sales (GFK, 2015)	Mobile phone subscriptions (ITU, 2016)	End-of-life mobile phones
2003	-	7274000	-
2004	3141000	7992000	2423000
2005	3489000	8665000	2816000
2006	3290000	9281000	2674000
2007	2991000	9912000	2360000
2008	3090000	10816000	2186000
2009	3030000	11434000	2412000
2010	3140000	12241000	2333000
2011	3320000	13022578	2538422
2012	3267000	13588000	2701578
2013	3341000	13272000	3657000
2014	3278000	12952605	3597395
Average	3216091		2699854

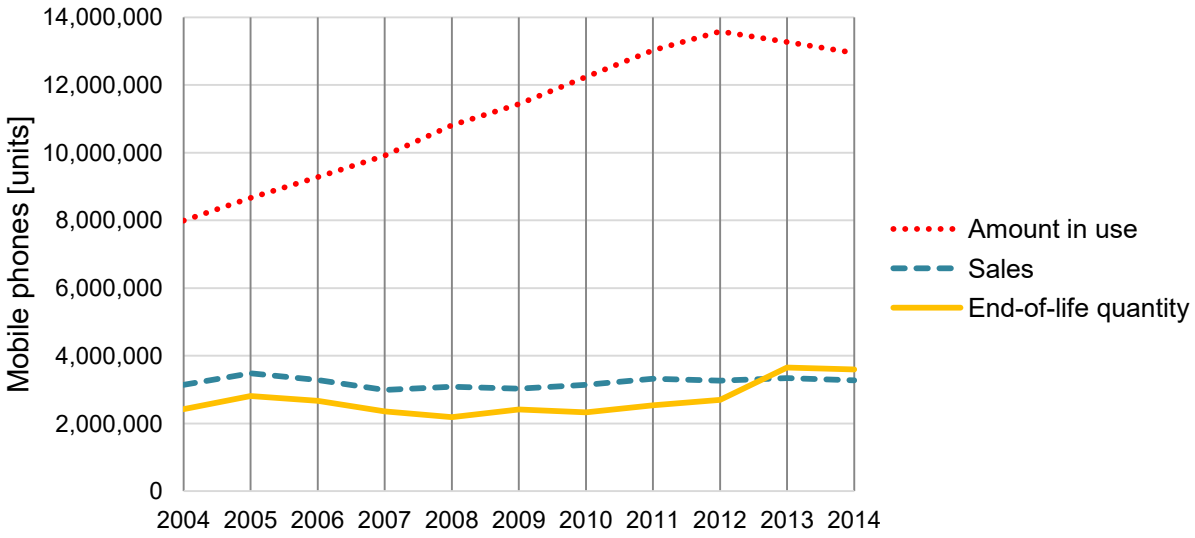

Figure 2. Sales, stock and end-of-life quantities of mobile phones in Austria (based on data from GFK, 2015; ITU, 2016)

It is important to note that the result of the time step method does not represent the actual number of mobile phones Austrian customers dispose of via official collection and take-back points for WEEE. Rather, these figures stand for the annual waste potential or gross waste quantity for mobile phones, which is defined as the quantity that is originally generated at the waste producer (WALK, 2011; SALHOFER, 2001). In order to identify the paths of obsolete mobile phones, consumer surveys on usage and disposal behaviour are useful (JANG & KIM, 2010). For Austria, WIESER & TRÖGER (2015) investigated the use phase and disposal of durable goods with a special focus on mobile phones. The study is based on an online survey with 1,009 participants, who are living in Austria and are members of a market research panel, and subsequent semi-structured interviews of 25 households. Due to quota sampling, the results can be regarded representative for the population between 18 and 65 years concerning gender, age, level of education and other criteria (WIESER & TRÖGER, 2015).

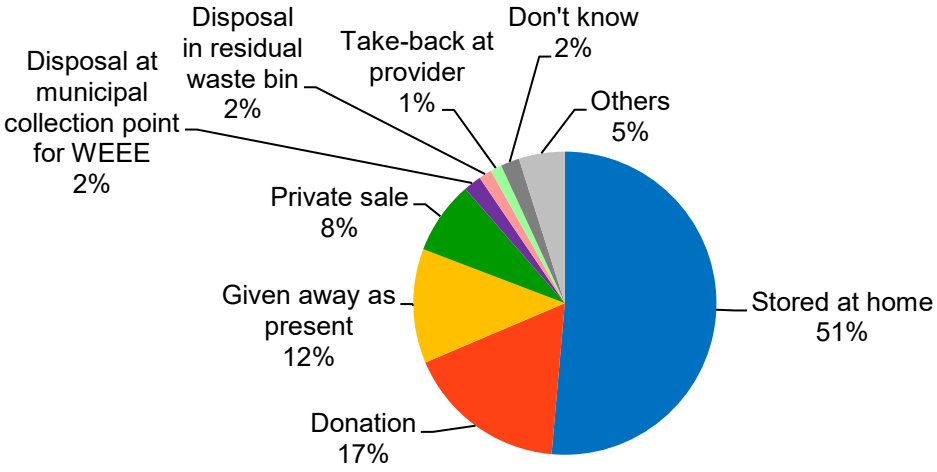

Figure 3. Disposal options for used mobile phones of Austrian consumers (modified from WIESER & TRÖGER, 2015)

As can be seen from Figure 3, the majority of Austrian consumers keep and store their old mobile phones at home after they ceased using them. Only 2 and 1 % of

respondents choose official municipal collection points for WEEE and trade-in programmes of service providers respectively. Also, the high share of people who donate their device to charity is remarkable (17%), which can be explained by the well-known charitable collection scheme of the “Ö3-Wundertüte”. As used mobile phones are still working in many cases, one fifth of respondents reported either giving them away as a present (12 %) or selling them (8 %).

When multiplying these fractions of chosen disposal options with the estimates of end-of-life mobile phones calculated by the time step method, it is possible to quantify the paths of used devices per year. Results are displayed in Table 5. From 2004 to 2014, an average of 1.39 million devices is stored at home per year. Approx. 460,000 devices are donated to charity, which corresponds well with the collection quantities of charitable organisations in reality. Being the largest charitable collector of used mobile phones, the “Ö3-Wundertüte” programme reported a total amount of 4.8 million collected devices from 2005 to 2016 (see chapter 3.3.3), which results in approx. 400,000 units annually. It can be assumed that devices that are given away as presents, for example, to family members and friends or that are sold privately can be considered as fully functional and usually do not undergo prior testing procedures, which are common practice at charitable collection and refurbishing initiatives or take-back programmes of service providers. These mobile phones, which total up to 540,000 units per year, are regarded to be directly reused and, hence, do not fall under the formal definition of waste in terms of the European Waste Framework Directive (NEITSCH et al., 2010). Particular concern should be placed on the fact that although separate collection systems for WEEE are in place, approx. 38,000 units are disposed of via residual waste per year, which means a loss of secondary resources. Mobile phones that are donated, disposed of at official collection points for WEEE or taken back by providers represent a separately collected waste stream. This adds up to a mean value of roughly 550,000 units per year. Related to an average amount of 3.22 million units put on the market annually, this results in a share of 17 % only and is, therefore, lower than the current collection rate for WEEE in Austria. From 2013 to 2015, on average 47.4 % of the amount of electrical and electronic equipment put on the market was collected (BMLFUW, 2017).

Table 5. Quantified paths of mobile phones after first use in Austria between 2004 and 2014 (units)

Year	End-of-life mobile phones	Stored at home	Donation	Given away as present	Private sale	Collect-ion point for WEEE	Residual waste bin	Take-back at provider
2004	2423000	1245422	416756	295606	188994	46037	33922	29076
2005	2816000	1447424	484352	343552	219648	53504	39424	33792
2006	2674000	1374436	459928	326228	208572	50806	37436	32088
2007	2360000	1213040	405920	287920	184080	44840	33040	28320
2008	2186000	1123604	375992	266692	170508	41534	30604	26232
2009	2412000	1239768	414864	294264	188136	45828	33768	28944
2010	2333000	1199162	401276	284626	181974	44327	32662	27996
2011	2538422	1304749	436609	309687	197997	48230	35538	30461
2012	2701578	1388611	464671	329593	210723	51330	37822	32419
2013	3657000	1879698	629004	446154	285246	69483	51198	43884
2014	3597395	1849061	618752	438882	280597	68351	50364	43169
Average	2699854	1387725	464375	329382	210589	51297	37798	32398

3.2 Collection systems of mobile phones in Austria

Several organisations are involved in collecting used mobile phones in Austria. Therefore, this chapter will provide an overview of those actors.

3.2.1 Mandatory collection

As end-of-life mobile phones constitute waste, they fall under the legislative framework for WEEE. As stipulated in the European WEEE directive (2012/19/EU), producers and distributors of electrical and electronic equipment are financially responsible for the collection and treatment of end-of-life devices. In order to comply with this obligation, distributors in Austria are required either to set up an individual system or to join a collective producer responsibility scheme, through which end users are able to dispose of their used appliances free of charge (BMLFUW, 2017). Currently, five collective systems for WEEE are registered in Austria (BMFLUW, 2016). Furthermore, according to the Austrian Waste Management Act ("Abfallwirtschaftsgesetz"), municipalities and municipalities associations, respectively, are obligated to establish collection points for WEEE from private households. Moreover, retailers with a sales area of more than 150 m² need to take back used equipment from end users on a one-to-one basis as regulated in the WEEE Ordinance ("Elektroaltgeräteverordnung"). Hence, end-of-life devices are typically taken back through municipal civic amenity sites and retailers (BMLFUW, 2017). In the specific case of mobile phones, common collection locations include shops of telecommunication providers and consumer electronics retailers. Some municipalities, such as the city of Vienna, also provide mobile collection services of small WEEE and hazardous materials from households, where used mobile phones are accepted.

As mobile phones are included in the category of small WEEE in official statistics, detailed collection results for the whole country are not available. In 2015, 80,246 t of WEEE were collected, of which 30,978 t or 3.6 kg/cap account for small WEEE (BMLFUW, 2017). As an example of municipal collection, the city of Vienna registered a total amount of 622 kg end-of-life mobile phones in 2015 (HOWORKA, 2016), which represents approx. 0.34 g/cap. Assuming an average weight of 0.1 kg per device, this results in 6,220 units or roughly 3 units per 1,000 inhabitants. The results of the time step method indicate that roughly 51,000 mobile phones or 6 units per 1000 inhabitants are disposed of via municipal WEEE collection points in Austria per year.

Despite the relatively high share of precious materials in mobile phones, collective producer responsibility systems are required to charge fees from their members in order to cover the costs for collection and processing of end-of-life equipment. Concerning the tariff class for small appliances, where mobile phones are included, fees range from 0.031 to 0.05 €/kg (ERA, 2017; INTERSEROH AUSTRIA, 2017) and from 0.01 to 0.02 €/unit (UFH, 2017). The value of end-of-life mobile phones is heavily impacted by commodity prices as well as the device's type and material content. While older types of mobile phones featuring keypads and associated gold contacts are currently traded for 6-10 €/kg, modern smartphones with touchscreens, whose content in precious metals is lower, are only worth below 3 €/kg (NAGL, 2016).

The treatment process of collected WEEE consists of manually dismantling easily removable parts and depollution, before applying shredding and sorting techniques

for material separation (NAGL, 2016; BMLFUW, 2017). Typical fractions after mechanical crushing and separation of mobile phones are aluminium, magnesium, zinc, ferrous material, plastics, glass and copper-PCB-concentrate, which is rich in precious metals (NAGL, 2016).

3.2.2 Voluntary collection

Besides the take-back of mobile phones that is required by law as part of the general collection of WEEE, several voluntary programmes that specifically focus on mobile handsets could be identified in Austria. These schemes are run by charitable or environmental organisations, commercial take-back companies, electronics retailers or mobile network providers and differ in their motivation for set-up. While charities seek to raise funds to support their projects, specialised take-back enterprises identified collecting and refurbishing used electronics as a commercial activity. Retailers and telecommunication providers aim at offering an additional service for their customers and at demonstrating environmental commitment.

While being legally responsible for the 1:1 take-back from end users free of charge, several distributors of mobile phones voluntarily established trade-in programmes, through which consumers are able to return their old devices. Telecommunications providers “A1” and “T-Mobile”, which represent a combined market share of more than two thirds (RTR, 2017), take back used functional smartphones in exchange for vouchers or discounts. Customers can bring their devices to any shop, where employees assess the residual value depending on type and condition. In general, the highest prices are paid for popular models with recent dates of production. Damages on buttons, displays or on the cover as well as the presence of a SIM lock, obviously, reduce the reuse value. If the model is not functional or obsolete and, therefore, excluded from the trade-in programme, it is taken back for recycling free of charge by means of collection boxes in store (A1, 2016; T-MOBILE, 2016). Hence, “A1” and “T-Mobile” go beyond the legal obligation and collect used mobile phones without requiring customers to purchase a new device. Additionally, both companies donate to charitable and environmental projects for every phone collected (A1, 2016; T-MOBILE, 2016). Both network operators cooperate with specialised take-back companies, which are in charge of processing and recirculating the collected models on second-hand markets. Reusable phones are frequently exported to Asian markets, where they are extensively refurbished before being resold as second-hand devices worldwide (SAGMEISTER, 2016).

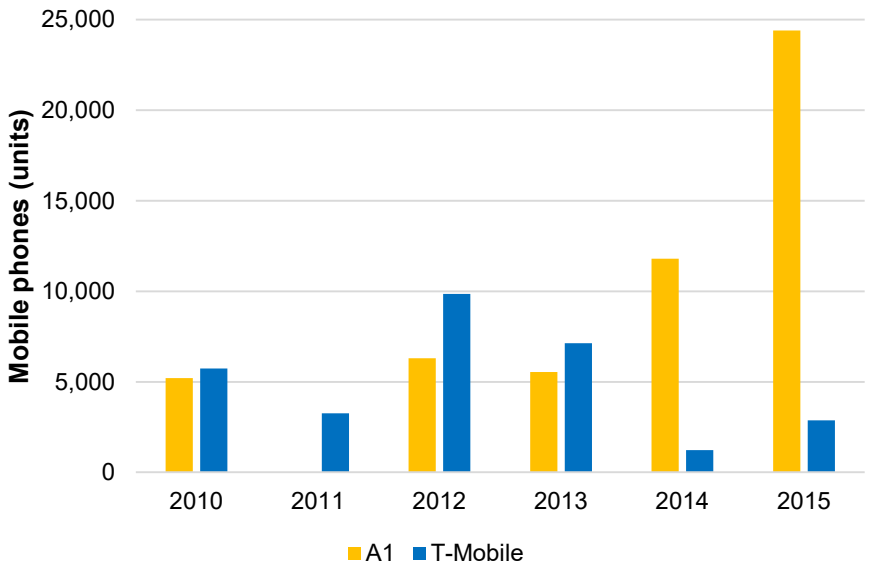

Figure 4. Amounts of end-of-life mobile phones collected by Austrian telecommunication providers A1 and T-Mobile (based on data from A1, 2016, 2015, 2014, 2013, 2010; T-MOBILE, 2016; T-MOBILE, 2013)

Since the introduction of its phone recycling programme in 2004, “A1” registered a total amount of more than 80,000 units (A1, 2017). Recent available collection results are displayed in Figure 4. It can be seen that the quantities taken back by “A1” increased sharply since 2014, when the trade-in programme was launched. Additionally, transparent collection boxes were placed in the provider’s shops and were, therefore, made visible to the customers at the point of sale. Moreover, the company launched a collection competition between its shops, whereby the staff received prizes if it succeeded in collecting the highest amounts. This way, employees were incentivised to ask consumers more actively to hand in their old phone when purchasing a new one. Hence, the company intended to increase awareness of both customers and employees (SCHWARZBAUER, 2016). According to “A1”, approx. 60 % of the mobile phones collected are still functional. Quantities taken back through the trade-in programme mainly consist of modern smartphones, while those devices collected through in-store recycling boxes are predominantly of older age of more than three or four years (SAGMEISTER, 2016).

Apart from mobile network providers, also several retailers collect mobile phones beyond the 1:1 take-back obligation. Just like “A1” and “T-Mobile”, electronics retailers “Hartlauer”, “MediaMarkt” and “Saturn” as well as mobile handset and services provider “Handyshop” cooperate with take-back companies in order to offer trade-in programmes for used functional smartphones in exchange for vouchers or cash (HARTLAUER, 2016; MEDIAMARKT, 2017; HANDYSHOP, 2017). The device is evaluated by employees in-store or can be sent in by post. Additionally, “MediaMarkt” and “Saturn” provide in-store collection boxes and envelopes in support of the charitable initiative “Ö3-Wundertüte” (APA, 2016a), which will be discussed in more detail in chapter 3.3.

Commercial take-back companies buy used mobile phones as well as other types of ICT and consumer electronics from end users in order to resell these devices for reuse (AK WIEN, 2017). Examples of businesses operating in Austria include for instance “asgoodasnew electronics GmbH” (“wirkaufens.at”), “FLIP4NEW” (“flip4new.at”), “Upcom Telekom Vertriebs GmbH” (“altehandys.at”), “Greenwire

Worldwide Ltd." ("zonzoo.at") or "Pikko-bello" ("diehandysammlung.at"). Typically, these companies operate an online trade-in platform, through which end users access a database and select the model they wish to sell. After being sent in by post free of charge, the device's condition is evaluated. If the phone is functional and of sufficient resale value, the buy-back price is transferred to the customer. Some take-back enterprises establish and operate trade-in platforms and take care of the reverse logistics in cooperation with retailers and mobile network operators, such as "Pikko-bello" with "A1", "T-Mobile" and "Hartlauer" or "FLIP4NEW" with "MediaMarkt" and "Saturn". Functional handsets are typically sold to wholesale traders, who refurbish them in Asia. The second-hand devices are then often redistributed in Asian and African countries (AK WIEN, 2017).

Apart from the "Ö3-Wundertüte" campaign, which due to collection volumes and media coverage can be regarded the most widespread system in Austria, there are several other charitable programmes. Here, the main incentive for end users to hand in used mobile phones is to support a charitable or environmental organisation by making non-monetary donations. In general, the NGO promotes the campaign. Technical tasks concerning collection, logistics, testing and redistribution, however, are undertaken by partners. The "Jane Goodall Institute Austria", for instance, is cooperating with the producer responsibility organisation for WEEE "UFH" and the socioeconomic enterprise "BAN". "UFH" is responsible for organising the collection, i.e. delivering and picking up collection boxes, while "BAN" is in charge of testing and sorting the devices (LEIZINGER, 2015). Functional mobile phones are exclusively sold in reuse shops within Europe so that the route of second hand devices from collection to second use remains transparent and accountable (TRÖSTL, 2015; LEHNER, 2015). Modern smartphones, for which there is still sufficient demand in Austria, are redistributed domestically (LEIZINGER, 2015). For every mobile phone collected the "Jane Goodall Institute Austria" receives donations of € 1 from the recycling partner "UFH", which are used to fund projects for the protection of chimpanzees and humanitarian aid (JGI-A, 2017). The collection mainly takes place at schools, which are provided with boxes from "UFH" and educational material prepared by the NGO. The top three schools, which collect the highest quantities, are awarded prizes (JGI-A, s.a.). End users can also bring their old phones to currently three locations in Vienna including the institute's office (JGI-A, 2017). The collection results of the last years range between 2,500 and 3,500 units per year (LEIZINGER, 2015). Another charitable campaign in Austria is "Tolle Tonne", which raises donations for "Herzkinder Österreich", an organisation that supports children suffering from a heart condition. Mobile phones are collected by means of boxes, which are set up in cooperation with partners. Across the country there are currently 158 locations including businesses, supermarkets, retailers, hospitals, fitness centres and municipalities, where end users can drop off old devices free of charge (TOLLE TONNE, s.a). Since the start of operation in 2014, approx. 10,000 mobile phones were collected. Testing, data erasure and sorting is done by partner companies based in Germany and Romania. About 15 to 20 % of the total quantity is deemed suitable for reuse. These devices are redistributed via aforementioned routes, i.e. on second-hand markets worldwide. The remaining 80 to 85 % is recycled within Europe (MEIER, 2017).

3.3 Case study “Ö3-Wundertüte”

3.3.1 Organisation and operation

“Ö3-Wundertüte” is a nation-wide charitable collection programme for used mobile phones in Austria established in 2005. It is based on a cooperation of radio station “Hitradio Ö3”, social service organisation “Caritas Österreich”, Austrian post, and packaging and paper manufacturer “Mondi”. Used devices are collected primarily by means of paper bags, which are sent to Austrian households during the weeks before Christmas and can be dropped off at every post office or post box free of charge. Moreover, schools are called upon to collect mobile phones via boxes and to take part in a year-round contest. Civic amenity sites in Upper Austria also provide separate collection boxes. In addition, the programme gladly accepts mobile phones donated from companies, which can be sent in using a free shipping label. Finally, consumer electronics retailers “Media Markt” and “Saturn” are participating in the programme and provide collection bags and boxes in-store (APA, 2016a).

The programme is organised and promoted by “Hitradio Ö3”, a nation-wide radio station belonging to public service broadcaster ORF. With a market share of 38 % in 2015 (RTR, 2015), “Ö3” is the country’s leading radio broadcaster. The Austrian post is in charge of logistics, which most notably comprises sending collection envelopes to households and shipment to the processing partner. “Mondi” sponsors the campaign by providing the paper bags. The collected mobile phones and accessories are processed by “magdas Recycling”, which is part of the social business enterprise “magdas” founded by Caritas Vienna. Twelve formerly long-term unemployed persons sort and test the devices for reusability. Proceeds from reselling mobile phones for reuse and recycling are donated to the charitable organisations “Caritas” and “Licht ins Dunkel” in support of families in need. On average, € 1.50 are donated per unit. Functional and reusable devices generate € 3.00, while those in defective condition make € 0.50 (LOSSMANN-ILIEV, 2016). Overall, donations of € 6.5 million were raised in eleven campaigns since 2005 (APA, 2016a).

3.3.2 Treatment of collected mobile phones

All mobile phones donated to the programme are centrally processed in Vienna, which is illustrated in Figure 5. In a first screening step, clearly defective or obsolete units are sorted out for recycling. This concerns approx. 20 % of the total collection quantity. The remaining devices are examined in detail in terms of functionality, optical condition and reparability of minor damages. Mobile phones that cannot be switched on are excluded from further tests, which is the case for yet another 20 %. Hence, approx. 40 % of the collection amount is sorted out for recycling. 60 % is deemed suitable for resale on second-hand markets. Depending on condition these mobile phones are assessed according to four classes. Devices in categories A and O pass the functional test and can therefore be regarded as fully functional, which is why they are considered as one class in this thesis. The separate classification is due to internal reasons. Functional devices requiring minor repairs because of, for example, defective power-on buttons or charging sockets are graded as B. Finally, category G contains mobile phones whose display is broken but otherwise in working order. This typically concerns smartphones with broken glass screens (LOSSMANN-ILIEV, 2016).

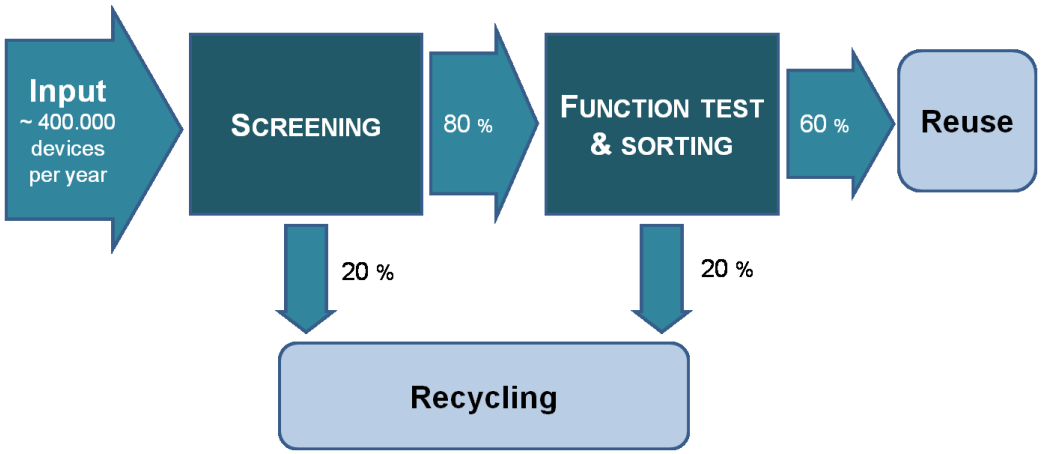

Figure 5. Sorting process for mobile phones collected by the "Ö3-Wundertüte"

3.3.3 Collection quantities

Since the programme was established in 2005, around 4.35 million mobile phones were collected in total. As can be seen from Figure 6, annual amounts range from 310,000 to 470,000 units with a mean value of almost 400,000. In the years from 2011 to 2015, for which in-depth collection data was available for analysis, quantities decreased slightly.

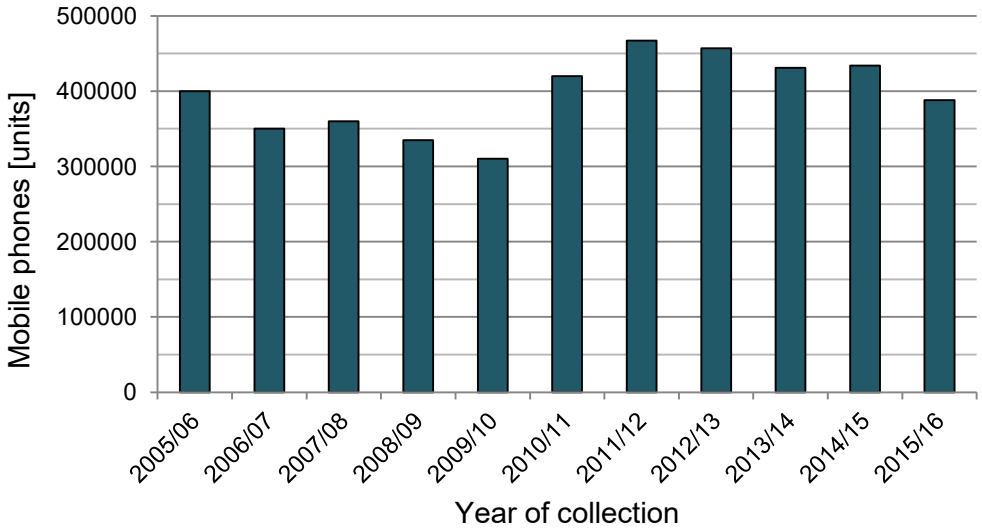

Figure 6. Total annual quantities of mobile phones collected by "Ö3-Wundertüte" (based on APA, 2016b, 2015, 2014, 2013, 2012, 2011, 2010, 2008, 2007, 2006; LOSSMANN-ILIEV, 2016)

In the five-year period, a total of 2.2 million mobile phones was recovered (Table 6), which results in 440,000 units on average per year. Approx. 66 % of the total collection amount is classified for reuse and, accordingly, 34 % are sent to recycling facilities. More than every second mobile phone that is donated to the programme falls into categories A and O and is therefore fully functional. Minor repairs are required for almost 14 %.

Table 6. Quantities of mobile phones per sorting category collected by “Ö3-Wundertüte” from 2011 to 2015 [units]

Collection period	Reference year	Total collection	Reuse	Reuse sorting category		
				A+O	B	G
Dec 2010 - Nov 2011	2011	420000	260704	161013	84381	15310
Dec 2011 - Nov 2012	2012	467000	315120	244040	49161	21919
Dec 2012 - Nov 2013	2013	457000	305110	253237	33550	18323
Dec 2013 - Nov 2014	2014	431000	295889	250250	27829	17810
Dec 2014 - Nov 2015	2015	434000	273180	242230	17650	13300
Total		2209000	1450003	1150770	212571	86662
Share of total collection (%)		100.00	65.64	52.09	9.62	3.92

A+O… device passes functional test
B… device passes functional test but requires minor repair (e.g. defective power-on button, charge socket etc.)
G… device passes functional test, functional display with optical defect (broken glass)

In total, 34 different brands were processed between 2011 and 2015, however, as Figure 7 shows, more than 90 % of the total reuse quantity falls upon three brands only, which are Nokia, Sony Ericsson, and Samsung.

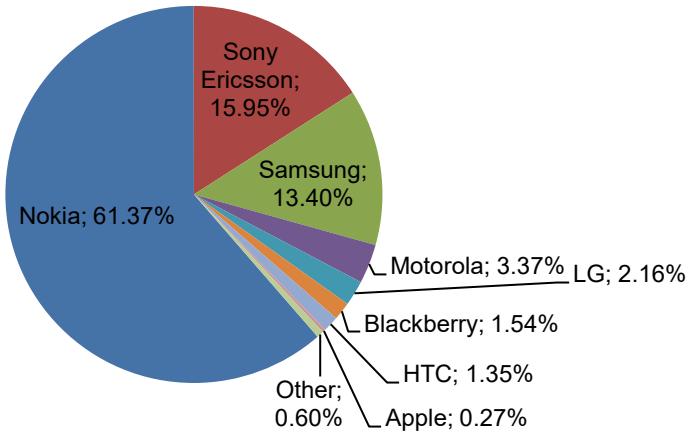

Figure 7. Proportion of brands in total reuse quantity from 2011 to 2015

The database excerpt included 420 different mobile phone models, which account for 90 % of the total reuse quantity. More than one fifth of this amount is determined by ten models only. With 45,134 units between 2011 and 2015 Nokia 3510i is the model that is most frequently classified for reuse, followed by Nokia 3310 (including version 3330) in second (44,988 units) and Nokia 6230i in third place (39,306 units). Smartphones are collected in relatively low amounts representing only 9 % of the total reuse volume on average. However, this share increased continuously during the five years under review from 4 % in 2011 to 12 % and 18 % in 2014 and 2015 respectively.

The mean weight of mobile phones including batteries is 95.3 g, which does not vary considerably between the five years. Smartphones weigh 114.0 g on average with a standard deviation of 17.5 g and are therefore heavier than feature phones with 93.4 g and a standard deviation of 14.9 g.

3.3.4 Lifetime analysis

As Figure 8 shows, the average total lifespan of reusable mobile phones has increased over the five years of observation. From 6.4 years in 2011 the mean value rises to 8.0 years in 2015, which amounts to an increment of 25 %. The average total lifespan between 2011 and 2015 is 7.2 years.

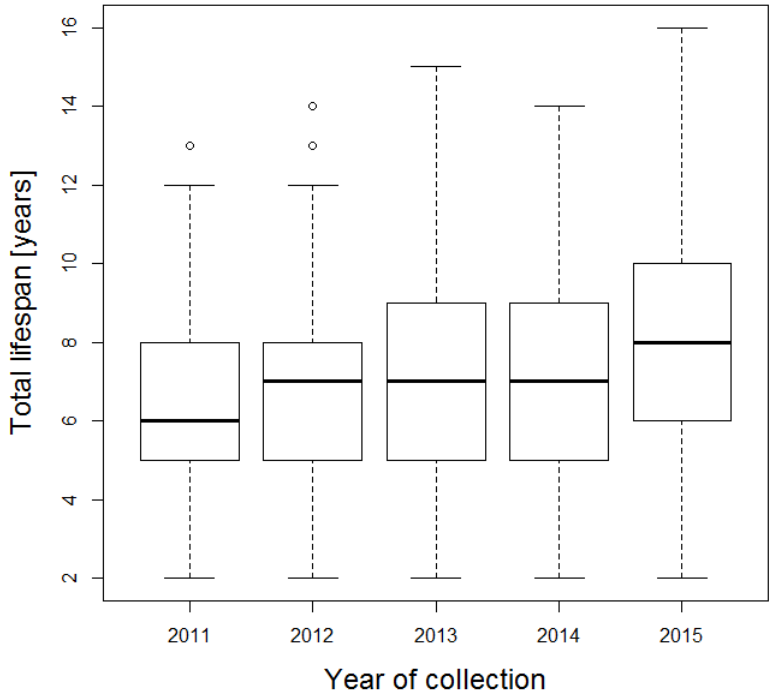

Figure 8. Boxplots of total lifespan of reusable mobile phones per year of collection

The reason for increasing lifespans can be attributed to the fact that older models with release years prior to the mid-2000s are still sent in to the programme in high numbers. This brings about that the share of older models in the annual collection quantity increased as displayed in Figure 9. While in 2011 only around 5 % of the collection result comprises models older than or equal to ten years, in 2015 this share increased to almost 20 %. At the same time more recent devices become less abundant. One fifth of the models received in 2011, for example, is younger than or equal to four years, however, in 2015 this is the case for only every tenth mobile phone. Hence, the average annual lifespan is increasing over the five years of observation as the quantities of younger mobile phones tend to decrease while once popular models of the first half of the 2000s still make up a significant share of the input. This suggests that older models such as the Nokia 3510, 3310 or 6230 are still stockpiled in Austrian households in high amounts. Although the stock of these unused devices decreases, they will continue to be handed in or disposed of for several years in relevant dimensions as is exemplarily illustrated in Figure 10.

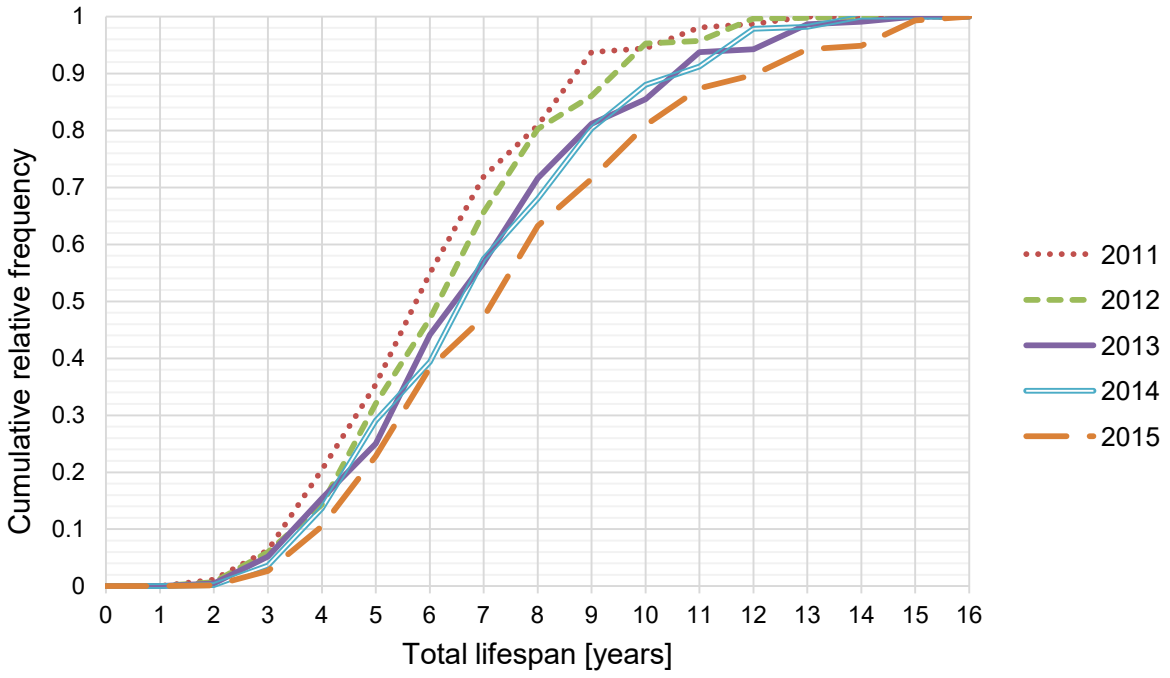

Figure 9. Cumulative relative frequencies of the total lifespan for the collection years 2011 to 2015

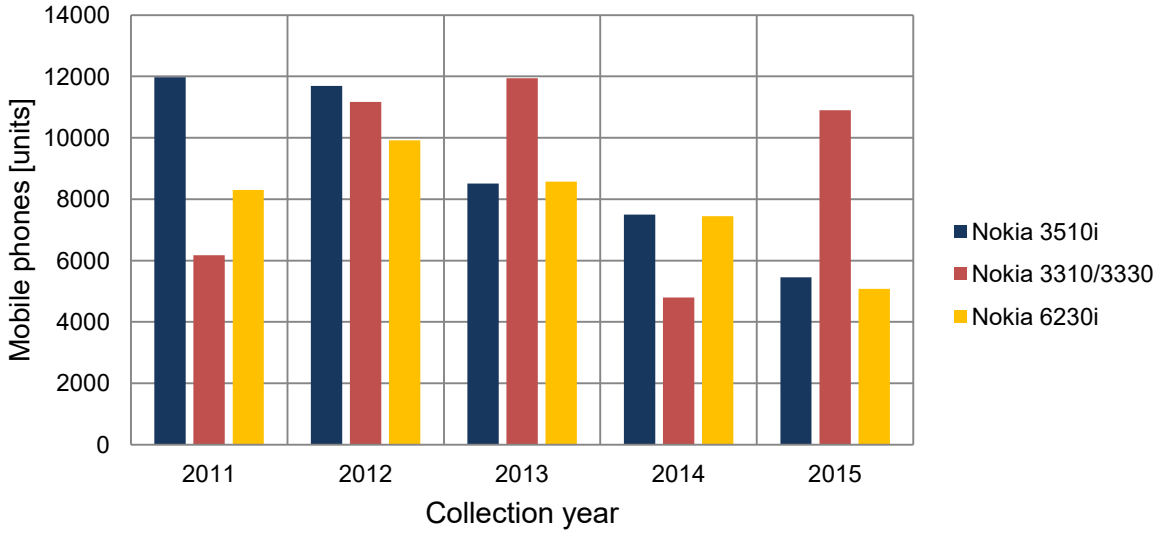

Figure 10. Collection quantities of models Nokia 3510i, Nokia 3310 & 3330 and Nokia 6230i between 2011 and 2015

As can be seen from Figure 11, the lifetime distribution is unimodal and right-skewed featuring a longer tail to the right, i.e. towards higher lifespans until a maximum of 16 years. No models younger than two years were included in the database excerpt.

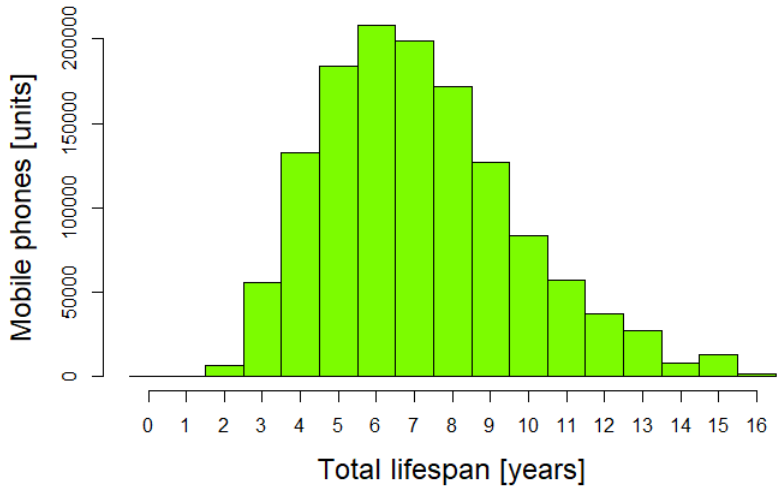

Figure 11. Histogram of lifespan data of total reuse quantity between 2011 and 2015

The parameters of the Weibull distribution calculated by maximum likelihood estimation are 8.03 for the scale and 2.94 for the shape parameter. Figure 12 shows the empirical cumulative distribution function together with the fitted Weibull distribution function. It can be seen that the theoretical distribution does not provide a perfect fit to the raw data. Consequently, tests for evaluating the goodness of fit such as chi-squared or Kolmogorov-Smirnov test produce a negative outcome with p-values far below 0.05. This is due to the vast extent of input data with more than 1.3 million devices, where even small deviations from a theoretical distribution cause the null hypothesis to be rejected.

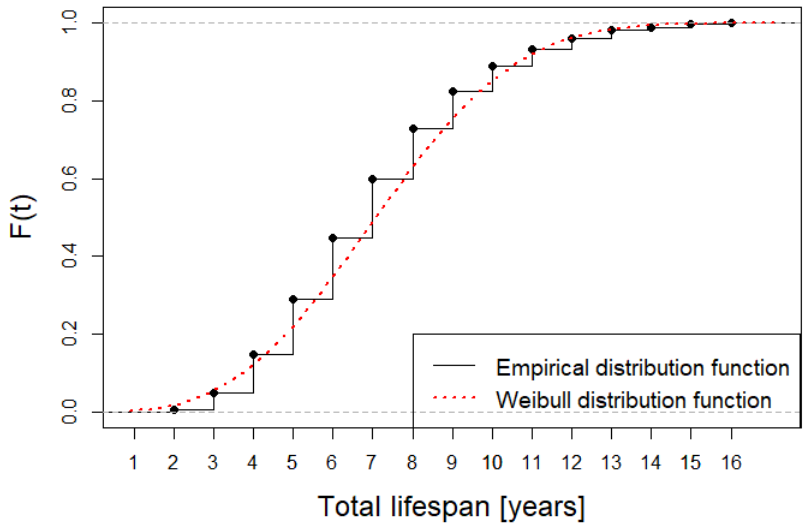

Figure 12. Empirical density function of total lifespan data (2011-2015) and fitted Weibull distribution function with scale = 8.03 and shape = 2.94

Analysing lifetime data according to model type shows that collected smartphones with 5.4 years on average are significantly younger than feature phones with 7.3 years (Table 7). Figure 13 indicates further that the mean total lifespan of smartphones is declining. However, due to comparably low quantities of collected

smartphones the overall trend of increasing lifespans of feature phones is not compensated. This suggests that while a higher share of older devices was collected from 2011 to 2015, the programme was successful in recovering an increasing amount of modern smartphones with relatively recent dates of production.

Table 7. Average total lifespan of reusable smartphones and feature phones between 2011 and 2015

Type	2011	2012	2013	2014	2015	Total
Feature phones	6.5	6.8	7.4	7.6	8.6	7.3
Smartphones	6.0	6.0	5.4	5.3	5.3	5.4
Total	6.4	6.8	7.3	7.3	8.0	7.2

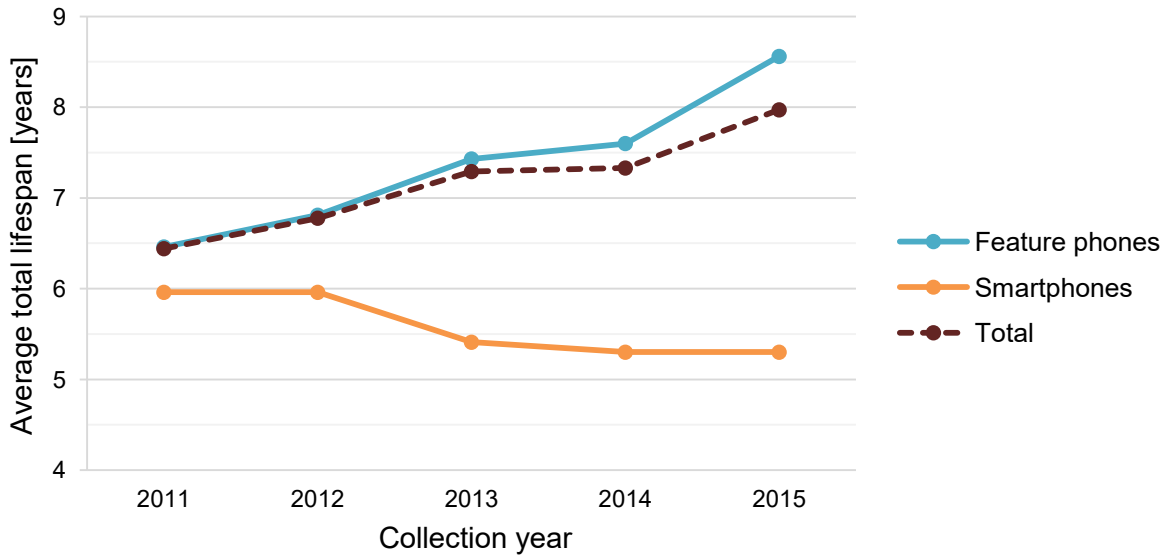

Figure 13. Plot of means of lifespan for feature phones and smartphones between 2011 and 2015

Mobile phones that are classified as fully functional (categories A and O) show higher total lifespans than devices requiring minor repairs (B and G). While lifespans in category A and O increased considerably from 6.8 in 2011 to 8.2 years in 2015, mean values of class B and G devices remained relatively stable with overall 6.0 and 5.3 years respectively (Table 8).

Table 8. Means of total lifespan per sorting category between 2011 and 2015

Sorting category	2011	2012	2013	2014	2015	Total
AO (fully functional)	6.8	7.1	7.6	7.6	8.2	7.5
B (minor repair required)	6.1	5.9	5.9	6.0	5.9	6.0
G (glass damage)	4.7	5.3	5.6	5.6	5.3	5.3

There is a consistent trend for the five years under review: the share of mobile phones classified as B and G decreases with higher lifespans (Figure 14), which is also true on the level of individual models. This suggests that minor damages or signs of wear are accepted for devices of younger age rather than for older models. In other words, slightly defective mobile phones are more likely to be classified for reuse the more recent their date of production is. Since market prices for used mobile handsets generally decline with increasing lifespans (GEYER & DOCTORI BLASS, 2010), this indicates that repair work is not deemed profitable for older models, where revenues from resale apparently cannot compensate additional efforts for repairs.

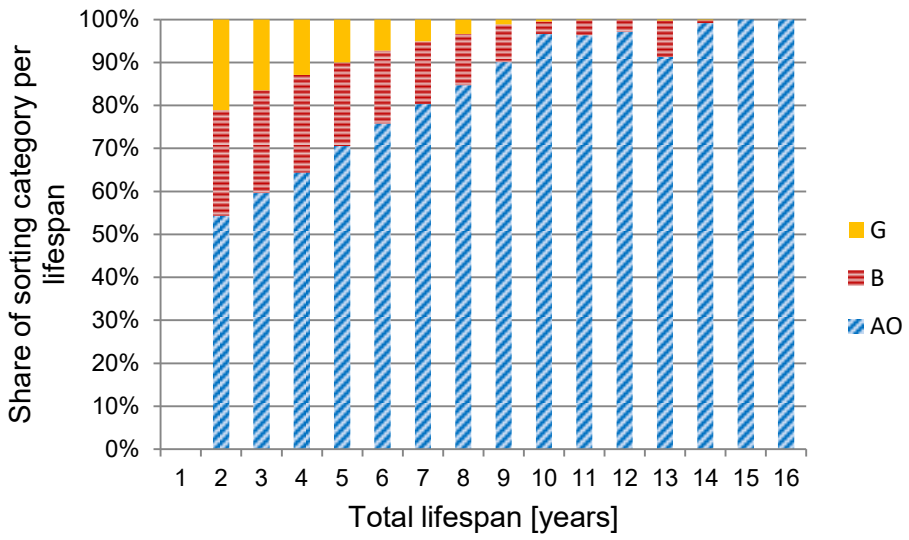

Figure 14. Proportion of sorting category per lifespan based on collection years 2011-2015

3.4 Interim conclusion

As was also shown by ONGONDO & WILLIAMS (2011a) for the UK, there are several different actors involved in the collection of mobile phones in Austria. Manufacturers and distributors of mobile phones generally join one of currently five collective producer responsibility organisations in order to comply with legal obligations concerning the take-back and treatment of end-of-life equipment. While being legally responsible for the 1:1 take-back, several telecommunication providers and electronics retailers go beyond this obligation and accept used devices without requiring their customers to purchase a new one. As a high share of used mobile phones is potentially suitable for a further use, several take-back companies are operating online trade-in platforms to buy back devices for refurbishment and resale. Also several charitable organisations identified collecting mobile phones as a fundraising tool. These actors collect used mobile phones by several methods:

- Public drop-off points (bring system)
- Collection by post
- Collection at schools
- Collection at workplaces

Public drop-off points are set up by municipalities at civic amenity sites and by distributors of mobile handsets at the point of sale. The charitable initiative “Tolle Tonne” provides a network of collection boxes at several locations such as supermarkets, fitness centres, retailers, and hospitals. In general, disposing of used phones at these drop-off points is free of charge. However, concerning the take-back in retail, the majority of sales outlets of mobile phones require purchasing a new device. Collection by post is offered by commercial take-back companies. Consumers that wish to sell their devices through one of the trade-in platforms reviewed are able to use free shipping labels provided. A more convenient way is offered by the campaign “Ö3-Wundertüte” in the form of reply-paid envelopes, which are sent to every Austrian household. The charitable initiatives of the Jane Goodall Institute Austria and the “Ö3-Wundertüte” specifically approach schools, which are provided with boxes as well as educational material and which have the chance to win prizes in a collection competition. Finally, several actors address businesses in

order to collect company mobile phones at the workplace. The charitable programmes “Tolle Tonne” and “Ö3-Wundertüte” as well as several commercial take-back enterprises provide collection boxes for companies and free pickup by courier.

4. Analysis and comparison of international collection systems for mobile phones

This chapter aims at analytically comparing collection systems for obsolete mobile phones on an international level in order to provide insights into aspects such as organisation, take-back method, performance and funding. Based on this evaluation, potential factors of success in terms of collection quantities are identified.

4.1 WEEE collection system

Once mobile phones have reached their end-of-life, they are constituted as WEEE. As such, end users in many countries worldwide are able to dispose of their used devices at official WEEE collection points. Comparably high collection results per capita are achieved by European countries (BALDÉ et al., 2015). Therefore, several European official take-back schemes are analysed in this section.

In the European Union, producers and distributors of EEE are financially responsible for the collection and treatment of end-of-life equipment as stipulated in the WEEE directive (2012/19/EU). Furthermore, manufacturers are required either to establish an individual take-back system or to take part in a collective scheme (STEWART, 2012). As the WEEE directive does not prescribe how it is to be transposed into national legislation, member states and collection systems are able to specify the exact details concerning organisation, collection method and responsibilities concerning collection and financing (CORSINI et al, 2017; KHETRIWAL et al., 2011; SANDER et al., 2007). While some individual brand-based take-back systems exist mostly for business customers (KHETRIWAL et al., 2011), the predominant compliance model for WEEE in Europe is the collective scheme, whereby manufacturers establish a producer responsibility organisation (PRO), which organises the collection and recycling of end-of-life equipment on behalf of its members (CORSINI et al, 2017). According to KHETRIWAL et al. (2011), collective systems can be classified into two types depending on the number of product categories they recover. Multi-sector compliance schemes collect a wide range of different equipment types. Often all categories listed in the WEEE directive are covered. Examples include “El-Kretsen” in Sweden, “elretur” in Denmark, “Elretur” in Norway, “Recupel” in Belgium or “Swico Recycling” in Switzerland. Single-sector compliance schemes, however, concentrate on one product category such as IT- and telecommunication or lighting equipment. Systems which are relevant for the collection of mobile phones are e.g. “ICT-Milieu” in the Netherlands (KHETRIWAL et al., 2011).

Compliance schemes are usually established by manufacturers, importers and retailers of EEE (referred as “producers”) and by corresponding industry and trade associations respectively, and operate on a not-for-profit level. In order to finance take-back and treatment of used devices, however, the producers are required to pay a variable fee. This recycling fee reflects the costs associated with the collection and treatment of the type of equipment and is calculated either per unit or per kg of the amount placed on the market. Typically, this fee amounts to several Euro cents. In Switzerland producers have to pay the equivalent of € 0.092 per mobile phone put on the market (SWICO, 2017), Belgian “Recupel” sets the price to € 0.050 per unit

(RECUPEL, 2016) and devices for the Dutch market are charged with € 0.040 to € 0.058 per kg depending on the total quantity per year (WECYCLE, 2016).

Physical collection in Europe is predominantly carried out by municipalities, which are legally obligated to take back WEEE in many European countries such as Denmark, Norway or Sweden (ROMÁN, 2012). In general, compliance schemes maintain partnerships with municipal collection points in order to manage financing and transport to recycling facilities (DEFILLET et al., 2013; SANDER et al., 2007). Certain collection systems also provide recycling containers for the collection of small WEEE, which are typically located at highly frequented places such as supermarkets or sales outlets. In Belgium, for instance, over 1,500 of such collection points were installed in 2015 (RECUPEL, 2015.). Retailers and distributors of electrical and electronic equipment are required by the WEEE Directive to take back used items from consumers on a one-to-one basis, i.e. when a new one is purchased. This collection channel plays an important role in Ireland, where many retailers accept all types of WEEE regardless of a like-for-like purchase. As a result, 51 % of the total collection result in 2015 was recovered through retail sites (WEEE IRELAND, 2016). Also customers in Switzerland have the option to hand in used products in-store without having to buy a similar device (ROMÁN, 2012). In Belgium and France reuse centres represent another relevant collection channel. Used equipment that is donated by consumers is tested for reusability, refurbished and sold on second-hand markets. Irreparable devices are transferred to the compliance scheme for recycling (DEFILLET et al., 2013).

In general, mobile phones are collected together with other types of electrical and electronic appliances, usually as part of the category of IT- and telecommunication equipment. As collection systems for WEEE are primarily recycling-orientated, reuse of mobile phones or other used equipment is not stipulated. The possibility of reuse is above all reduced by damages that are likely to occur during bulk collection and storage (MPPI, 2009b). Reuse of equipment is reported from France and Belgium, where reuse centres play a relevant role in the collection of WEEE.

According to the WEEE directive, collection rates are only prescribed for WEEE in total (EUROPEAN COMMISSION, 2014). Hence, specific targets for product categories or even individual equipment types such as mobile phones are not formulated. Therefore, exact statistics on the number of collected and recycled mobile phones are rarely publicly available. In the Netherlands, approx. 1 % of the amount of ICT equipment collected by “ICT Milieu” in 2016 and 2015 constitutes tablets and mobile phones (ICT MILIEU, 2016; ICT MILIEU, 2017), which results in roughly 105 t and 124 t or 6.2 and 7.3 g/cap respectively. In Switzerland, quantities of collected mobile phones are recorded separately. As can be seen from Figure 15, the take-back quantities of retired handsets increased steadily by more than twice the amount in 2009. In 2016, approx. 710,000 units or 143 t of used mobile phones were collected by the system of “Swico” (SENS/SWICO/SLRS, 2017). This equals 17.2 g/cap or 85 units per 1,000 inhabitants.

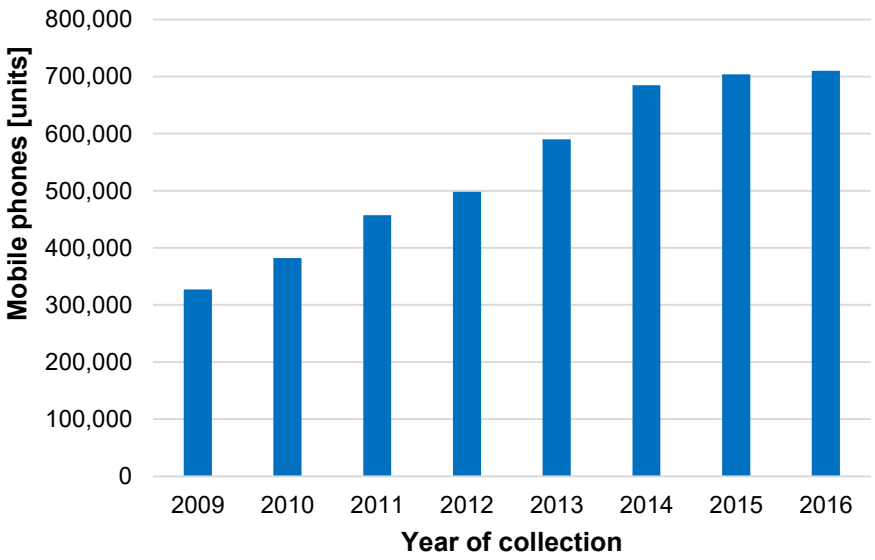

Figure 15. Quantities of end-of-life mobile phones collected by "Swico" between 2009 and 2016 (based on data from SENS/SWICO/SLRS, 2017, 2016, 2015, 2014, 2013, 2012)

4.2 Branch Systems

Contrary to official WEEE collection systems, which accept a wide range of different types of electrical and electronic appliances, branch systems focus solely on the take-back of mobile phones. These voluntary initiatives are founded and organised by a trade association, which represents the country's mobile telecommunications industry, i.e. most notably handset manufacturers and network providers (BEIGL et al., 2012). For this section, the branch systems "MobileMuster" in Australia, "Recycle My Cell" in Canada and "RE:MOBILE" in New Zealand were analysed.

Founded in 2014 by the New Zealand Telecommunication Forum (TCF) "RE:MOBILE" is the youngest scheme compared to "Recycle My Cell" and "MobileMuster", which were established in 2009 and 1998 by the Canadian Wireless Telecommunications Association (CWTA) and the Australian Mobile Telecommunications Association (AMTA) respectively (TCF, 2015; CWTA, 2010; AMTA, 2015). All three initiatives aim at ensuring responsible end-of-life management for used devices by setting up a collective system for their members and to provide a free take-back service for customers.

Besides mobile phones, branch systems also accept associated accessories such as chargers or headphones, handset batteries and mobile broadband modems. The take-back network consists of drop-off points, where customers can dispose of their old device through collection boxes free of charge. Typical locations are shops of network providers and retail outlets, however, branch systems also seek the participation of council offices, public institutions like museums and libraries, non-governmental organisations and schools, which are provided with boxes or bins, posters and other promotional material. Additionally, companies in Australia and New Zealand are encouraged to set up collection containers for their employees (AMTA, 2016; TCF, 2016). The total number of public drop-off locations in New Zealand is 311 (TCF, 2016), which results in one site per approx. 15,200 inhabitants. Canadian "Recycle My Cell" offers one take-back point per roughly 14,100 people or 2,493 in total in 2016 (CWTA, 2017). The Australian "MobileMuster" initiative, however, set up

the densest collection network in relation to population size with 4,600 public drop-off locations in 2014/15 including network providers, retailers and local councils sites (AMTA, 2015). This amounts to one point per 5,100 inhabitants. In addition, 2,100 workplaces and 500 schools cooperated with the programme in 2015/16 (AMTA, 2016). Alongside drop-off points, the branch systems also receive retired mobile phones by post. Customers are able to send in their device using a pre-paid shipping label, which is downloadable from the programmes' websites. Moreover, in Australia pre-paid collection bags are available at post offices and are also included when buying a new phone from a participating manufacturer (AMTA, 2015). Finally, "MobileMuster" and "Recycle My Cell" regularly organise collection campaigns in order to raise awareness about mobile phone recycling and to increase participation. In Canada, contests for students (CWTA, 2015a) as well as for non-governmental and community organisations (CWTA, s.a.) are held annually, in which prices are awarded to those who collect the highest amount. Every year "MobileMuster" campaigns for increasing publicity and raising money for a good cause. In the period 2015/16, AU$ 2.00 per kilogram of mobile phones collected in a two-month period were donated to the Salvation Army (AMTA, 2016). Experience from the Australian case shows that in 2014/15 about one third of the total volume was collected by drop-off points of network providers and mobile phones retailers. Another third was sent in by mail, which steadily gained importance since the introduction of reply-paid bags in 2008. About 10 % stemmed from other retail outlets and the remaining quarter fell upon service centres, council sites and others (AMTA, 2015).

Branch systems use several ways to promote the scheme and to increase public awareness such as posters and brochures at drop-off points, press releases, newsletters, social media, and advertising campaigns. All schemes under review aim at engaging schools, which are provided with educational material about mobile phone recycling. Apart from communicating ecological benefits from recycling such as preservation of resources or pollution prevention, the programmes cooperate with charitable organisations in order to provide an additional incentive to return used devices. These organisations receive donations either from the scheme's proceeds as in New Zealand (TCF, 2016) or as a fixed amount per quantity collected as in Australia (AMTA, 2016).

Recent collection results from "MobileMuster" show that the Australian scheme collected 76.1 t of mobile phone components in 2015/16, which divides into 42 % handsets, 37 % accessories and 22 % batteries. This amounts to 31,699 kg or approx. 420,000 units of handsets (AMTA, 2016). New Zealand's "RE:MOBILE" was able to recover 122,762 units in 2014/15 and 105,317 units in 2015/16 (TCF, 2016). Since 2005, Canadian "Recycle My Cell" as well as previous member initiatives collected a total of 7,068,464 devices (CWTA, 2017), which is an average of approx. 590,000 units per year from 2005 to 2016. The latest announced result from 2016 is 649,503 devices (CWTA, 2017). For the purpose of comparison, available collection data is calculated in relation to population size, which is presented in Figure 16. Note that results from Australia and New Zealand, where the fiscal year commonly ranges from July to June, are referred to the year, where the collection period ended. Hence, the quantity of mobile phones recorded e.g. in the period 2015/16 is depicted as 2016 in order to facilitate comparison.

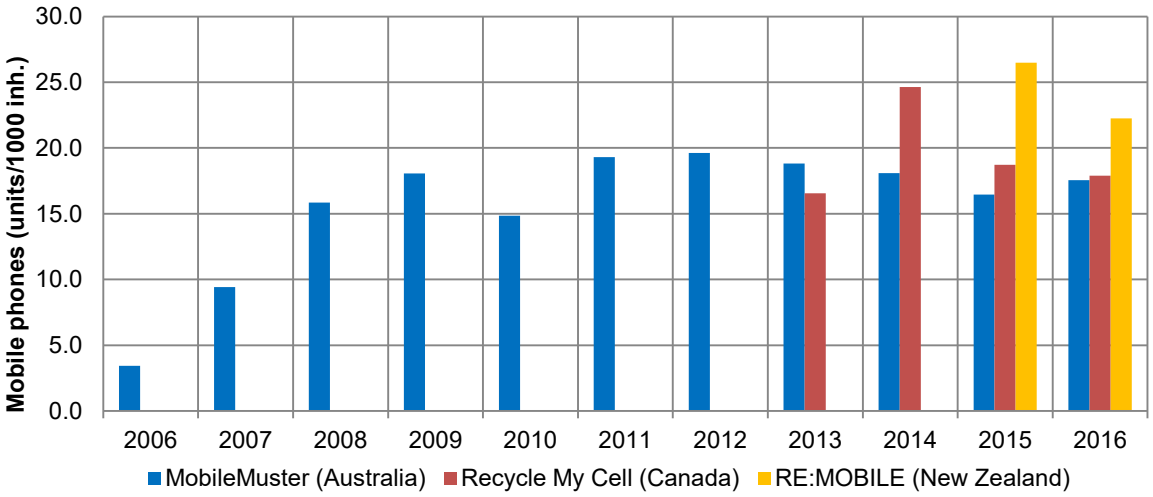

Figure 16. Number of end-of-life mobile phones collected per 1,000 inhabitants (based on data from AMTA, 2016; AMTA, 2015; CWTA, 2017, 2016, 2015b, 2014; TCF, 2016)

For the years 2013 to 2016, where data for all three systems was available, the number of mobile phones that branch systems were able to recover varies from roughly 16 to 27 units per 1,000 inhabitants. As Figure 16 shows, the highest quantity per capita was achieved in New Zealand with 24 devices on average over the last two years, followed by Canada with a mean of 19 units since 2013. With approx. 18 devices per 1,000 inhabitants Australia comparably features the least quantity, which is surprising at first sight given the fact that "MobileMuster" has set up the densest collection network in terms of population. One possible explanation may be found when considering the population density. Australia is the least densely populated country (3 inh./km²) compared to Canada (4 inh./km²) and New Zealand (17 inh./km²) (WORLD BANK, 2017b). Another reason for high take-back results in New Zealand may be the fact that prior to the establishment of "RE:MOBILE" a charitable collection campaign, which was operating for more than six years, already had raised awareness about the importance of mobile phone recycling (see chapter 4.4).

Apart from recycling, the branch systems in Canada and New Zealand also consider the possibility of reuse. For this purpose all collected devices are centrally processed by a specialised commercial take-back company. Usual treatment steps include sorting, data cleansing and performance checks. Defective and obsolete mobile phones are sent to e-waste recycling facilities, while those devices that meet all functionality criteria are sold on second-hand markets worldwide. As reported from New Zealand, possible locations where handsets are remarketed are Hong Kong, China and Eastern Europe (TCF, 2016). Australian "MobileMuster" prohibits to reuse devices once they are collected as the scheme's intended purpose is to provide end-of-life management for its members. Therefore, the entire collection amount is shipped to e-waste recyclers for dismantling and material and energy recovery. Nonetheless, the system cooperates with commercial reuse programmes and provides the take-back of devices for recycling (AMTA, 2016). Aside from that, some participating network and service providers independently offer trade-in services in Australia, where customers can hand in reusable handsets in exchange for discounts.

The question whether used mobile phones are partly reused or exclusively recycled has clear implications for the programme's funding. At "Recycle My Cell" and

“RE:MOBILE” operational costs are covered by revenues from reselling used devices for reuse and recycling. In practice, the cooperating refurbishing company pays a fee for each phone collected to the scheme (TCF, 2016). At “MobileMuster”, however, all devices are sent to recycling facilities. As revenues from material recovery compensate for only 2 % of the programme’s costs (AMTA, s.a.), additional funds are required. Consequently, “MobileMuster” requires its members to pay an annual recycling fee. For 2015/16, this amount ranges from AU$ 0.12 per unit shipped into Australia for network carriers and AU$ 0.30 for handset producers (AMTA, 2016), which converts to approx. € 0.08 to 0.21.

4.3 Commercial refurbishing

Commercial refurbishing systems are set up by private companies, which specialise in the reverse logistics of used electronics. The business model, which is also called recommerce (HAHLER & FLEISCHMANN, 2015), consists of collecting or buying used functional electronic equipment from individuals, businesses or other organisations, in order to reprocess and remarket them as second-hand products. Unlike many other types of retired electrical and electronic equipment used mobile phones are a sought after commodity on second-hand markets worldwide (GEYER & DOCTORI BLASS, 2010), which is why numerous commercial take-back schemes have been established. For this section refurbishing companies based in Australia (“PhoneCycle”), Canada (“Greentec”), France (“Recommerce Solutions”), Ireland (“Swapkit”), the Netherlands (“Ecowave BV”), the UK (“bak2 Group”, “Corporate Mobile Recycling”, “Mazuma Mobile”) and the USA (“The Wireless Alliance”, “GRC Wireless”) were evaluated.

Commercial refurbishing companies either exclusively take-back mobile phones or accept a range of other electronic products as well including laptops, tablets and mp3/mp4-players. The service portfolio typically ranges from trade-in websites for consumers, management of reverse logistics for retailers and mobile network operators, fundraising for charities and occasionally sales platforms to put reusable devices back on the market. Consequently, these take-back enterprises play a central role in collecting and handling retired mobile phones (GEYER & DOCTORI BLASS, 2010).

The process of buying back from consumers and businesses is carried out online via the recommerce provider’s trade-in website. Prospective sellers access a database containing a continuously updated list of models for which a provisional price is offered depending on condition. Generally, only rather recent smartphones are listed in the database, as these are still deemed marketable. Obsolete or defective devices are excluded from the buyback option, but may still be accepted by some refurbishing companies at no cost. Reshipment usually takes place free of charge by using shipping labels or by courier for larger quantities. Business customers may also contact the operator directly to enquire about a quote.

Refurbishing companies usually undertake the management of reverse logistics on behalf of network providers and retailers by providing the tools for in-store and online trade-in programmes, delivering collection containers and arranging shipment. Hence, used devices are collected either directly through the in-house buyback website or indirectly via retailers and network providers.

Commercial collectors frequently seek to extend their collection channels by offering take-back programmes for charities, non-governmental organisations, schools and

other public institutions. Provided with boxes and promotional material these groups may initiate their own collection campaign in order to raise funds for their activities. The refurbishing company takes care of picking up the containers once they are full. Especially for charities and non-governmental organisations this cooperation represents an additional way of collecting donations, while the recommerce company benefits from increased promotion and a better access to the stock of end-of-use mobile phones.

After being received and registered at the processing centre the devices pass through several steps. Defective handsets are usually sorted out if they fail to power-on. Reusable phones are tested further and graded according to condition. Any personal data left on the memory is erased. As reported from US-based refurbisher "GRC Wireless", approx. 60 % of the phones received are remarketed (GRC, 2017a). British "Corporate Mobile Recycling" reports a reuse yield of 70 % (CMR, 2014). The remaining 30 to 40 % are either defective beyond economic repair or obsolete and are sent to e-waste recyclers. Separated by brand and model the reusable devices are packaged and distributed on second-hand markets worldwide. In general, the majority of used mobile phones is sold in low and middle income countries in e.g. Africa, Asia and Eastern Europe (CMR, 2016), where further refurbishing and repair work may be undertaken. A certain percentage of devices, especially modern smartphones, are sometimes remarketed in countries where they were collected. For that reason, several recommerce companies are operating online stores.

Due to confidentiality reasons, exact data on collection quantities is only scarcely publicly available. UK-based "Corporate Mobile Recycling", which operates trade-in websites in ten European countries and Australia, processed a total of 556,050 units in 2014/15 (CMR, 2016), while in 2010/11 more than one million devices were recovered (CMR, 2015). Hence, in a period of five years collection quantities steadily decreased to currently almost half a million mobile phones. Unfortunately, these figures are not broken down by country. Since foundation in 2002 to 2016 "GRC Wireless" could collect 7 million units in the USA (GRC, 2017b) resulting in an annual average of approx. 467,000 handsets or roughly two units per 1,000 inhabitants. Australian "PhoneCycle" was able to recover over 50,000 units nationwide in 2015/16, which equals two mobile phones per capita as well (PHONECYCLE, 2016).

As a commercial activity, the take-back scheme is evidently entirely funded by revenues from reselling refurbished mobile phones for reuse and from material recovery. The value of reusable devices depends on condition and age as well as on make and model. Empirical data from US- and UK-based refurbishing companies shows that the average revenue from refurbishment and resale ranges from US$ 17 to 23 per handset in 2006 and 2003, while costs are around US$ 2 (GEYER & DOCTORI BLASS, 2010). However, according to UK-based buy-back comparison website "Compare My Mobile" (cited in DELOITTE, 2016), the average trade-in prices of used mobile phones increased from an average of US$ 30 in 2007 to US$ 165 in 2013. The market for second-hand devices thus developed significantly and is expected to grow further. GARTNER (2015) estimates that in 2017 120 million refurbished smartphones with a wholesale revenue of US$ 14 billion are sold on second-hand markets worldwide, which is more than twice the amount of 2014, where 56 million units worth US$ 7 billion were distributed. DELOITTE (2016) forecasts that the second-hand market for smartphones is currently expected to grow four times faster than the market for new smartphones. For 2016, consumers worldwide are predicted to sell and trade-in a total of 120 million smartphones,

whereby US$ 17 billion are paid out. Thus, end users receive an average of US$ 140 for their old device in 2016, which is an increase from US$ 135 in 2015 (DELOITTE, 2016).

4.4 Charitable refurbishing

Several branch systems and commercial take-back companies support environmental or social service organisations or offer customers the possibility to donate the value of their phones to a good cause in order to increase participation. Charitable refurbishing schemes, however, are defined here as systems whose primary aim is to raise funds to support charitable or environmental protection activities. This chapter is based on an evaluation of charitable collection initiatives based in Austria ("Ö3-Wundertüte"), France ("L'association POUR LA VIE"), Germany ("Handys für die Umwelt", "Mobile-Box"), Ireland ("Jack and Jill Foundation"), New Zealand ("Starship Foundation"), and the USA ("Cell Phones for Soldiers").

Usually, the system is based on a cooperation of the charity organisation, which is the scheme's beneficiary and promoter, with a commercial refurbisher as described in chapter 4.3. The processing partner is in charge of reverse logistics tasks, assesses the devices' quality and, depending on condition and model, resells them on worldwide markets for second-hand electronics or to e-waste recyclers. A share of the proceeds is transferred to the charity organisation. The programmes, therefore, enable people to support a charitable cause by making a non-monetary donation, which can be regarded the main incentive. Frequently, promotional activities also communicate environmental benefits such as preservation of primary resources or financing of nature conservation projects in order to motivate people to hand in mobile phones to the system.

With regard to collection, charitable systems choose the same methods as previously discussed programmes. The majority of initiatives under review facilitate sending in mobile phones by mail and provide drop-off points. Collection by post is frequently free of charge for the donator by using shipping labels downloadable from the programmes' website. Another option for sending in mobile phones is by pre-paid envelopes, which are delivered to households as by the Austrian "Ö3-Wundertüte" initiative (APA, 2016a) or which are regularly inserted in newspapers and magazines as arranged by the Starship Foundation in New Zealand (STARSHIP FOUNDATION, 2013a). Drop-off points are established in cooperation with partners such as telecommunication providers, supermarkets, public authorities, educational institutions, businesses etc., which set up collection boxes and associated promotional materials at their premises. In Germany, the programmes "Handys für die Umwelt" and "Mobile-Box" established a collection network of 1,500 (SOMMER, 2017) and 1,000 (MOBILE-BOX, 2017) public drop-off locations, which results in one point per roughly 54,000 and 82,000 inhabitants respectively. The US-based non-profit organisation "Cell Phones for Soldiers" provides 4,000 collection points across the country (CELL PHONES FOR SOLDIERS, 2017) or one per 80,000 people. New Zealand Starship Foundation's "Mobile Phone Appeal", which was suspended in 2015, provided the densest network of public drop-off points in terms of population. Collection boxes for mobile phones were set up at every store of the country's three network providers Spark, Vodafone and 2degrees, which are currently operating a total of 206 shops across New Zealand (SPARK NEW ZEALAND, 2017; VODAFONE NEW ZEALAND, 2015; 2DEGREES, 2017). Assuming that this figure has not

changed considerably since the programme's cessation in 2015, this results in one drop-off point per approx. 23,000 inhabitants. Another relevant collection channel is established in cooperation with schools, which some charitable campaigns seek to address with specific programmes. The "Starship Foundation" called on all schools in New Zealand to collect mobile phones in exchange for educational resources. In addition, the organisation collaborated with scout groups, which initiated door-to-door collections and promoted the campaign (STARSHIP FOUNDATION, 2013a). A similar campaign for schools was launched by the "Jack and Jill Children's Foundation" in Ireland (JACK & JILL FOUNDATION, 2009). The Austrian "Ö3-Wundertüte" initiative holds an annual contest for schools, which are provided with boxes and educational material about mobile phones (ÖSTERREICHISCHE CARITASZENTRALE, s.a.).

Once collected the devices are processed as described in chapter 4.3 by the cooperating refurbishing company. The majority of the schemes analysed report that reusable mobile phones are exported to countries in Africa, Asia and South America. Functional devices collected by the German schemes "Handys für die Umwelt" and "Mobile-Box" are mostly resold within Europe, which is the case for 10 to 20 % of the total collection amount (SOMMER, 2017; BUND, 2016; DUH, 2016). Reusable and marketable devices collected by the "Ö3-Wundertüte" in Austria make up 60 % of the total amount (LOSSMANN-ILIEV, 2016). Mobile phones that are either broken or obsolete are sold to e-waste recyclers.

Just like commercial schemes, the funding of charitable collection initiatives primarily relies on reselling used mobile phones on second-hand markets. Typically, the charitable or environmental NGO receives a fixed amount of money per collected device from the processing partner. Functional handsets collected by the Austrian "Ö3-Wundertüte" initiative, for instance, yield donations of € 3.00 per functional device, while € 0.50 are paid out for a defective one (LOSSMANN-ILIEV, 2016). The "Starship Foundation" in New Zealand received NZ$ 2.30 per phone on average in 6.5 years (STARSHIP FOUNDATION, 2015), which converts to roughly € 1.50. Devices collected through the German system of "Mobile-Box" generate donations between € 0.50 and € 1 per unit depending on the amount of reusable devices (SCHUMACHER & VON PIDOLL, 2016). Experiences from the German environmental organisation "Deutsche Umwelthilfe", which is the beneficiary of the initiative "Handys für die Umwelt", show that donations for each collected mobile phone declined. From € 5 in 2003 and € 3 in 2009 (DUH, 2004; DUH, 2009) the amount of donations per device decreased to currently less than one Euro (SOMMER, 2017). The collection schemes initiated by the "Starship Foundation" in New Zealand and the "Jack and Jill Foundation" in Ireland also report that the value of used mobile phones declined to such an extent that this way of fundraising is no longer deemed feasible. Consequently, both programmes were ended in 2015 (STARSHIP FOUNDATION, 2015; JACK & JILL FOUNDATION, 2015). According to the Starship Foundation, people are less willing to donate used smartphones but rather choose to sell them or to hand them on to family members and friends (STARSHIP FOUNDATION, 2015).

Publicly available collection results are summarised in Table 9. Unfortunately, the majority of the schemes under review do not communicate detailed information on quantities per year but only the total amount of mobile phones collected since the start of the initiatives. For the sake of comparison, these figures are divided by the length of the collection period, and subsequently related to the average population

size during this time span, which was retrieved from the database of the WORLD BANK (2017). Annual results available for the Austrian "Ö3-Wundertüte" campaign were summed up for all twelve collection years.

Table 9. Collection performance of analysed charitable refurbishing systems (based on data from APA, 2016b, 2015, 2014, 2013, 2012, 2011, 2010, 2008, 2007, 2006; LOSSMANN-ILIEV, 2016; STARSHIP FOUNDATION 2015; CELL PHONES FOR SOLDIERS, 2017; SOMMER, 2016; MOBILE-BOX, 2017)

Charitable refurbishing system	Collection period	Years of collection	Total quantity [units]	Average annual quantity [units]	Average annual quantity per 1000 inhabitants [units/1000 inh.]
"Ö3-Wundertüte" (Austria)	12/2005 - 12/2016	12	4,775,000	398,000	47
Starship Foundation "Mobile Phone Appeal" (New Zealand)	02/2009 - 08/2015	6.5	1,000,000	154,000	35
"Cell Phones for Soldiers" (USA)	2004 - 2016	13	15,000,000	1,154,000	4
"Handys für die Umwelt" (Germany)	2003 - 2016	14	2,300,000	164,000	2
"Mobile-Box" (Germany)	2016	1	40,000	40,000	0.5

As can be seen from Table 9 the highest collection results per capita are achieved by the Austrian scheme followed by the Starship Foundations appeal in New Zealand. Both programmes are characterised by extensive support of several partners. In Austria, the public radio station "Hitradio Ö3", which has the highest market share among all other national radio broadcasters, is promoting the campaign with reports, press releases and advertisement in TV, radio and print. Moreover, the Austrian post delivers freepost envelopes to every household during the weeks before Christmas. Hence, the programme is widely known in public (WIESER & TRÖGER, 2015). The New Zealand scheme was supported by all three network providers, which established in-store drop-off points, and by several bank branches, retailers, newspapers and magazines, which distributed reply-paid envelopes. In terms of population, the Starship Foundation's campaign had the densest network of public drop-off points among all other analysed charitable systems. While the systems in France, Germany and the USA enable sending in mobile phones using a pre-paid shipping label, the Austrian and New Zealand initiatives distribute freepost envelopes, which can simply be dropped into post boxes. This method is more convenient as the end user is not required to care for packaging and printing the shipping label. In addition, both systems receive significant quantities collected by schools. Since the "Ö3-Wundertüte" programme launched its school campaign in 2011, a total of 255,000 mobile phones was collected by pupils across Austria until 2016 (ÖSTERREICHISCHE CARITASZENTRALE, 2017, 2016, 2015, 2014, 2013, 2012). This amounts to an average share of 10 % of the total collection result for the six years. Schools in New Zealand supported the Starship Foundation with a total of 59,000 handsets in 2.5 years (STARSHIP FOUNDATION, 2013b), which equals an annual mean of 23,600 units. Assuming an overall annual collection result of 154,000 units, the charity therefore potentially sourced about 15 % through its schools campaign.

4.5 Comparison

In this section, the previously discussed collection systems are compared along the lines of the following criteria: organisation & operation, collection performance, collection method, treatment and funding.

In terms of organisation and operation, WEEE collection systems and branch systems are set up as collective schemes (BEIGL et al., 2012), where producer responsibility organisations or trade associations representing the mobile telecommunications industry take care of the collection and treatment of end-of-use equipment on behalf of their members. Commercial and charitable take-back systems, however, can be seen as individual schemes (BEIGL et al., 2012), which are operated by a third-party collector. These take-back companies' business model comprises the reverse logistics and refurbishment of used mobile phones. Thus, they play a central role in systems that intend to direct devices to reuse. While this is the case with commercial and charitable refurbishing programmes, the analysis shows that also the branch systems in Canada and New Zealand consider the possibility of reuse by collaborating with recommerce companies.

The collection performance is a crucial indicator for the programmes' success. For reasons of comparison, available collection quantities are related to the average population size as it is done in chapter 4.4. As can be seen from Figure 17 and Table 10, the Swiss system of "Swico" can be regarded the most successful. From 2009 to 2016, an average of 68 retired mobile phones could be recovered per 1,000 inhabitants. With 47 and 35 units, the charitable campaigns in Austria and New Zealand come in second and third among the reviewed schemes. The collection performance of the branch systems in Australia, Canada and New Zealand ranges from 16 to 24 devices per 1,000 people, while individual systems of commercial operators only recover low amounts around two units.

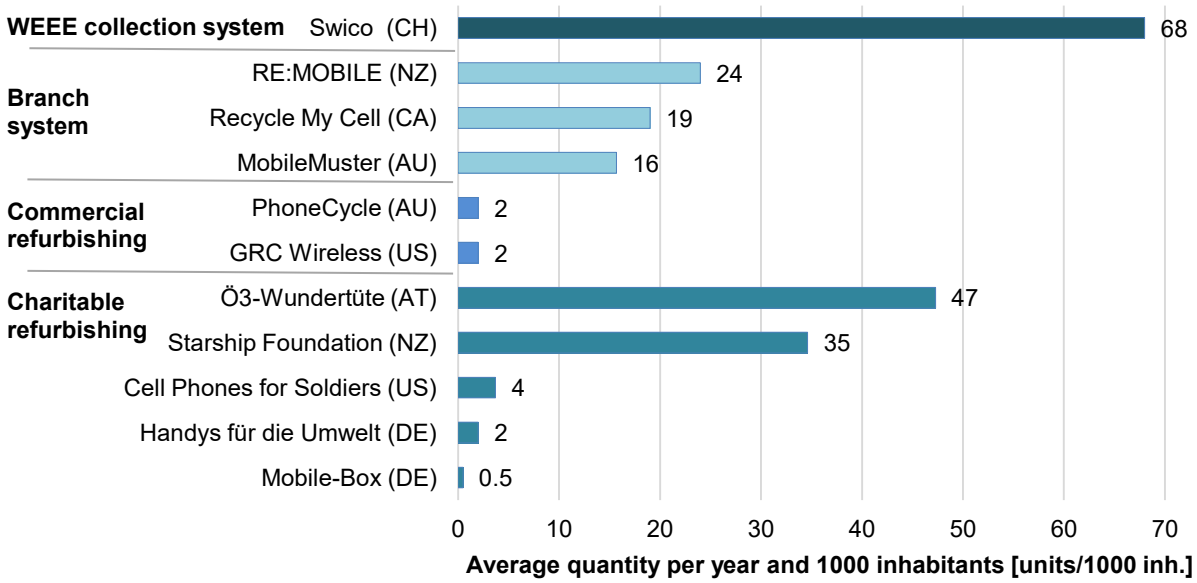

Figure 17. Average annual collection quantities (units per 1,000 inhabitants) (based on data from SENS/SWICO/SLRS, 2017, 2016, 2015, 2014, 2013, 2012; AMTA, 2016; AMTA, 2015; CWTA, 2017, 2016, 2015b, 2014; TCF, 2016; GRC, 2017b; PHONECYCLE, 2016; APA, 2016b, 2015, 2014, 2013, 2012, 2011, 2010, 2008, 2007, 2006; LOSSMANN-ILIEV, 2016; STARSHIP FOUNDATION 2015; CELL PHONES FOR SOLDIERS, 2017; SOMMER, 2016; MOBILE-BOX, 2017)

Table 10. Collection performance of analysed collection systems for mobile phones (based on data from SENS/SWICO/SLRS, 2017, 2016, 2015, 2014, 2013, 2012; AMTA, 2016; AMTA, 2015; CWTA, 2017, 2016, 2015b, 2014; TCF, 2016; GRC, 2017b; PHONECYCLE, 2016; APA, 2016b, 2015, 2014, 2013, 2012, 2011, 2010, 2008, 2007, 2006; LOSSMANN-ILIEV, 2016; STARSHIP FOUNDATION 2015; CELL PHONES FOR SOLDIERS, 2017; SOMMER, 2016; MOBILE-BOX, 2017)

Collection system	Collection period	Years of collec-tion	Total quantity [units]	Average quantity per year [units]	Average quantity per year and 1000 inhabitants [units/1000 inh.]
WEEE collection system					
Swico Recycling (Switzerland)	2009 - 2016	8	4,353,000	544,000	68
Branch System					
RE:MOBILE (New Zealand)	2014/15 - 2015/16	2	228,000	114,000	24
Recycle My Cell (Canada)	2013-2016	4	2,778,000	695,000	19
MobileMuster (Australia)	2005/06 - 2015/16	11	3,822,000	347,000	16
Commercial refurbishing system					
GRC Wireless (USA)	2002 - 2016	15	7,000,000	467,000	2
PhoneCycle (Australia)	2015/16	1	50,000	50,000	2
Charitable refurbishing system					
Ö3-Wundertüte (Austria)	12/2005-12/2016	12	4,775,000	398,000	47
Starship Foundation (New Zealand)	02/2009 - 08/2015	6.5	1,000,000	154,000	35
Cell Phones for Soldiers (USA)	2004 - 2017	13	15,000,000	1,154,000	4
Handys für die Umwelt (Germany)	2003 - 2017	14	2,300,000	164,000	2
Mobile-Box (Germany)	2016	1	40,000	40,000	0.5

One aspect affecting the amount of mobile phones recovered is the collection method chosen. All schemes under review provide drop-off points at various locations at e.g. civic amenity sites, retail outlets, stores of network providers, supermarkets etc. In Switzerland, consumers can hand in their used devices either at every retail store or at “Swico” collection points at no charge (KHETRIWAL et al., 2009). In total, the system offers approx. 6,000 public drop-off locations (SWICO, s.a.), which amounts to one collection point per roughly 1,400 inhabitants. Compared to other programmes such as the branch systems in Australia, Canada and New Zealand, which provide one point per 5,100 to 15,200 people, the Swiss scheme

established the densest network. High collection results may, however, not only be attributed to numerous drop-off locations, as the case of the Austrian "Ö3-Wundertüte" exemplifies. This initiative primarily collects mobile phones by means of reply-paid envelopes, which are sent to every household during the weeks before Christmas. The majority of the other schemes reviewed facilitates collection by post as well by offering pre-paid shipping labels. In this case, the end user has to download and print the label and care for suitable packaging. Using freepost envelopes, however, is a more convenient method as they can be dropped off at post offices and post boxes. Apart from the Austrian campaign, only the charitable programme by the "Starship Foundation" in New Zealand and the Australian branch system "MobileMuster" distribute reply-paid envelopes.

Another factor for encouraging people to return used handsets is public awareness. Collection schemes need to inform about the purpose of the programme, the importance of mobile phone recycling and how to dispose of retired devices. In Switzerland, the system of "Swico", which was founded in 1994, is the country's only take-back scheme for WEEE from ICT, consumer electronics, offices and other areas (STREICHER-PORTE, 2006). Hence, it can be considered a well-established and well-known system. Furthermore, according to KHETRIWAL et al. (2009) the fact that the advanced recycling fee is visible to the customer on the receipt when purchasing a new device contributes to creating greater awareness about the scheme and WEEE recycling. Above all, the system specifically addressed the issue of low return rates of retired mobile phones by intensifying its public relation activities and launching awareness campaigns (SWICO, 2008). The Austrian "Ö3-Wundertüte" campaign is regularly promoted by the nation's leading radio broadcaster "Hitradio Ö3" by reports, radio and TV commercials and advertisements across the country. Moreover, the collection envelopes, which every household receives by post, serve as promotional flyers themselves as they feature information about the programme. As a result, the "Ö3-Wundertüte" is a well-known initiative in Austria (WIESER & TRÖGER, 2015). Another method of creating greater awareness about the scheme is by specifically addressing schools and children, which is the case for the branch systems in Australia and Canada and for the charitable campaigns in Austria, Ireland and New Zealand. The schools may register for the programme to receive collection boxes, promotional material and educational resources. Some systems also hold collection contests and award prices. Children that are involved in collecting retired devices for their class or school learn about mobile phone recycling and are likely to inform their families about the programme. Besides the benefit of accessing an additional take-back channel, the schemes, therefore, also gain higher public awareness.

Once collected, the retired mobile phones are either exclusively recycled or inspected for reuse and partly refurbished depending on the scheme's primary aim. WEEE collection and branch systems are set up to ensure the controlled take-back and treatment of retired equipment and to provide end-of-life management on behalf of their members. Consequently, the prevailing treatment method is recycling. Nevertheless, the branch systems in Canada and New Zealand are designed to evaluate the reusability of collected handsets. Also in France and Belgium reuse centres represent an integral part of the official WEEE take-back schemes. Commercial and charitable refurbishing programmes primarily intend to divert mobile phones to reuse. According to commercial refurbishers and the Austrian "Ö3-Wundertüte", about 60 to 70 % of the total collection amount is suitable for further use (GRC, 2017a; CMR, 2014; LOSSMANN-ILIEV, 2016). These devices are

typically sold to traders of second-hand electronics worldwide and are eventually reused in countries in Africa, Asia, South America and Eastern Europe. Interestingly, two charitable programmes in Germany, which distribute functional devices mostly within Europe, report a share of remarketable handsets between only 10 to 20 % (SOMMER, 2017; BUND, 2016; DUH, 2016).

Whether the take-back system chooses to recycle only or to direct a share of the collected mobile phones to reuse is decisive for its funding. WEEE collection systems, which are geared to material recycling, are required to charge fees from its members in order to cover the costs for collection, transport and treatment. European producer responsibility organisations typically set the fee for mobile phones to several Euro cents. Based on data from Austria, Belgium, the Netherlands and Switzerland approx. € 0.01 to € 0.09 per mobile phone put on the market are charged (SWICO, 2017; RECUPEL, 2016; WECYCLE, 2016; UFH, 2017). The impact of not considering the possibility of reuse on the programmes' funding is best illustrated when comparing the branch systems in Australia, Canada and New Zealand. While similar in organisation, objectives and collection results, the programmes differ considerably in terms of funding. While the branch schemes in Canada and New Zealand are able to cover operational costs by reselling mobile phones for reuse and recycling, the Australian system requires additional funding from its members as revenues from material recycling alone are insufficient. Therefore, membership fees of converted € 0.08 to € 0.21 per unit put on the market apply (AMTA, 2016). Hence, systems that focus on reuse are able to operate profitably as testified by the abundance of commercial take-back enterprises for obsolete handsets. Second-hand mobile phones are a sought after commodity, whose market is expected to grow (GARTNER, 2015). Commercial refurbishing companies focus on the collection of modern smartphones, for which an average of US$ 140 per device is currently paid to users, who sell their old phones on buy-back platforms (DELOITTE, 2016). Charitable campaigns, however, accept all types of handsets and tend to receive a high amount of older models. Overall, these initiatives generate donations from € 0.50 to € 3.00 per handset depending on condition (LOSSMANN-ILIEV, 2016; SCHUMACHER & VON PIDOLL, 2016; SOMMER, 2017).

5. Trends and challenges for mobile phones collection systems

5.1 Profitability of collecting mobile phones

Experiences from international collection systems could confirm that mobile phone collection and reuse constitute a profitable commercial activity. Markets for used devices and, especially, smartphones have developed significantly and are expected to grow further (DELOITTE, 2016, GARTNER 2015). As pointed out by GEYER & DOCTORI BLASS (2010), mobile phone recycling can be regarded a by-product of refurbishing operations, as reverse logistics costs by far outweigh revenues from material recovery alone. Whether collection schemes aim at reuse or solely at recycling has, therefore, significant implications for the system's funding. The international review could show that systems that aim at diverting collected handsets to reuse are able to fund reverse logistics costs primarily by revenues from reselling second-hand devices. Official WEEE collection systems as well as the Australian branch programme "MobileMuster", where all devices are only recycled, are required to seek additional funding. Fees that are charged by these systems from participating manufacturers and retailers are typically around several Euro cents per mobile phone.

5.2 Material content of mobile phones

Due to fast technological evolution, mobile phones have been subject to significant changes in weight, size and material content. Over the last three decades, the devices' average mass has decreased substantially (MPPI, 2012). Data from the "Ö3-Wundertüte" campaign, which comprises models released from 1998 to 2013, could confirm that the average weight decreased steadily. While models released in 1998 have a mean weight of 150 g, devices produced in 2007 weigh only 84 g on average. However, as smartphones, which are significantly heavier than feature phones, become more popular, this trend started to reverse, which has also been observed by GUO & YAN (2017). On average, modern smartphones weigh around 120 g (CUCCHIELLA et al., 2015). However, despite an increase in mass, the content of precious metals tends to decrease. CHRISTIAN et al. (2014) analysed 85 mobile phones from 1998 to 2013. They conclude that the average content of gold and silver decreased from 0.04 to 0.03 g and 0.13 to 0.06 g, respectively. Due to low quantities of precious metals, the authors argue that the costs for recycling may not be compensated by the value of recovered materials unless the process is highly automated (CHRISTIAN et al., 2014). Also GEYER & DOCTORI BLASS (2010) predict that the trend of decreasing amounts of gold will continue, which is central for the profitability of material recovery. The share of revenues from the recovery of gold in the total recycling revenues is estimated to be 70 % for mobile phones (GEYER & DOCTORI BLASS, 2010) and 56 % for smartphones (CUCCHIELLA et al., 2015). The decline in the content of precious metals can be attributed to a higher degree of miniaturisation and a more efficient material usage (TRÖSTL, 2015). Even though modern smartphones are generally larger and heavier than devices of the last decade, the size of printed circuit boards, which contain the majority of precious metals, is declining (NAGL, 2016; LOSSMANN-ILIEV, 2016). Moreover, contrary to

touch screens of smartphones, the keypads of feature phones contain gold contacts (LEHNER, 2015; LOSSMANN-ILIEV, 2016). According to Austrian e-waste recycler "SMK", older feature phones are currently traded for 6-10 €/kg, while prices for recent end-of-life smartphones are below 3 €/kg (NAGL, 2016). This indicates that the profit margin of recycling end-of-life mobile phones is decreasing as modern smartphones become more abundant in the waste stream. Therefore, commercial and charitable collection systems, which aim at turning mobile phones into profits and donations, face the challenge of decreasing revenues for devices that are destined for recycling. This highlights the importance of collecting a high proportion of reusable phones in order to ensure the scheme's profitability. GEYER & DOCTORI BLASS (2010) estimate that the reuse yield should be at least 50 %. In practice, several collection systems analysed report a share of devices suitable for further use of around 60 % of the total quantity.

5.3 Consumption and disposal patterns of end users

As the resale value of second hand mobile phones decreases rapidly over time (GEYER & DOCTORI BLASS, 2010), it is essential for collection systems that are geared towards reuse to motivate people to hand in their old devices as soon as possible. However, end-of-use mobile phones are frequently stockpiled at home as indicated by various literature sources (SPEAKE & NCHAWA YANGKE, 2015; PANAMBUNAN-FERSE & BREITER, 2013; ONGONDO & WILLIAMS, 2011b; JANG & KIM, 2010). About half of Austrian and Swiss consumers, for example, report to have stored their old devices after use, frequently as back-up or because of valuable data on the memory (WIESER & TRÖGER, 2015; SWICO, 2016a). This behaviour has led to significant amounts of unused mobile phones hibernating in households. MURAKAMI et al. (2009) calculate that in 2007 167 million devices were stored in Japanese households, which results in roughly 1.3 phones per inhabitant. SENS/SWICO/SLRS (2012) values this amount at 8 million or about one end-of-use mobile phone per Swiss. For Australia, AMTA (2016) reports hibernating stocks of 25.5 million devices or roughly one unit per capita as well. In Austria, the results of the time step method combined with the consumer survey by WIESER & TRÖGER (2015) could reveal that every year on average 1.4 million mobile phones are stockpiled in households after consumers stopped using them, which amounts to an annual mean of approx. 0.2 units per inhabitant. Although no information on the time span of hibernation is available, in-depth collection data from the "Ö3-Wundertüte" campaign suggests that significant numbers of mobile phones remain unused for several years. According to WIESER & TRÖGER (2015), the average service life of mobile phones in Austria is 2.7 years. Compared with the mean total lifespan of 7.2 years for devices collected by the "Ö3-Wundertüte", it can be concluded that on average it takes 4.5 years until the programme receives the handset. During this period of time the phone may be reused domestically, but may as well be kept idle. While decreasing over time the campaign still receives high amounts of models released in the late 1990s and early 2000s. For the collection year 2015, for instance, almost 20 % of the annual quantity comprises models released before 2004. The consumers' stockpiling behaviour is one main challenge for mobile phone collection systems as emphasised, for example, by the Australian branch system "MobileMuster": "[...] overcoming Australia's hoarding behaviour to keep their old mobile 'just in case' is a major barrier to recycling" (AMTA, 2016). Even the case of "Swico", which collects the highest numbers of mobile phones in relation to population size among all other systems analysed, shows that the collection rate can

still be substantially improved. Based on data from EITO (cited in SWICO 2016b, 2015 & 2014), an annual average of 4.3 million smart and feature phones was put on the Swiss market between 2013 and 2015. Compared to 710,000 units collected by "Swico" in 2016 (SENS/SWICO/SLRS, 2017), this results in a collection rate of approx. 17 % only.

Moreover, several charitable initiatives report a change in people's willingness to donate their old mobile phone. The campaigns by the "Starship Foundation" in New Zealand and by the "Jack and Jill Foundation" in Ireland were discontinued because the value and supply of phones decreased (STARSHIP FOUNDATION, 2015; JACK & JILL FOUNDATION, 2015). According to the STARSHIP FOUNDATION (2015) people increasingly tend to sell or pass their smartphones on to family members and friends rather than donating them for a good cause. Also the programme by the "Jane Goodall Institute Austria" experienced that online trade-in platforms have become a serious competitor regarding valuable reusable smartphones (LEIZINGER, 2015). This trend, however, apparently does not affect the more widespread campaign of the "Ö3-Wundertüte", which reports stable annual collection quantities over the last years and even increasing amounts of relatively modern smartphones (see chapter 3.3.3).

5.4 Export of reusable mobile phones

Systems focusing on reuse frequently export functional mobile phones from the country of collection. Wholesale traders for used electronics are typically located in Asia such as in Hong Kong (DENG et al, 2017; AK WIEN, 2017). After being refurbished, second-hand devices are often redistributed in low- and middle-income countries worldwide, where markets for models of older age exist. Typical destinations for refurbished phones are Africa, South Asia and the Middle East (DENG et al, 2017). As these phones are generally cheaper than new ones, they provide affordable access to telecommunication for people in the lower income class, which has positive social impacts. People may use mobile phones to find work, to keep in touch with friends and relatives and, hence, to save travel cost, to seek medical advice or to set an alarm for taking medicine (JAMES, 2014). Furthermore, extending the use phase of mobile phones reduces the need for the production of new goods with associated negative environmental impacts and contributes to a more efficient resource use (WILHELM, 2012). However, low- and middle-income countries frequently lack effective legislation and collection systems concerning e-waste (MANHART et al., 2012). Once mobile phones reach their end-of-life they usually do not undergo environmentally sound treatment, but are either disposed of with mixed household waste and landfilled or recycled by the informal sector (BABAYEMI et al., 2017). Typical recycling procedures include manual dismantling, open burning and dissolution with strong acids to recover metals, which causes severe health and ecological problems (DENG et al. 2017; BABAYEMI et al., 2017; HERAT & PARIATAMBY, 2012). Open burning of e-waste causes the release of brominated flame retardants (BFR), heavy metals and persistent organic pollutants (POPs) such as PCDD/F with direct effects on the health of workers involved in informal recycling operations (BABAYEMI et al., 2017). Also, numerous authors such as ISIMEKHAI et al. (2017), TUE et al. (2013) and GIDARAKOS et al. (2012) detected high levels of heavy metals and organic pollutants in the soils surrounding informal e-waste recycling sites, which poses a serious health threat to the wider community as these pollutants contaminate agricultural produce such as rice

(ZHANG et al., 2012). As the route and fate of exported reusable mobile phones is rather intransparent, the collection campaign initiated by the “Jane Goodall Institute Austria” is the only system among all others reviewed that redistributes functional devices domestically (LEHNER, 2015). This decision obviously brings about that a smaller share of collected devices is remarketable as the sales potential for second-hand feature phones in Europe is lower than on the African or Asian market.

5.5 Factors for success

In terms of collection performance, collective systems like official WEEE collection and branch schemes turned out to achieve higher results than individual systems. This is due to the fact that collective efforts obviously are able to establish a denser network of public drop-off points and to launch more widespread promotional campaigns. Individual schemes that are operated by commercial take-back enterprises compete with other buy-back platforms over the amount of used devices. Moreover, commercial operators frequently only accept a share of the stock of end-of-use mobile phones, i.e. smartphones with relatively recent dates of release, as these generate the highest profits.

The analysis could show that individual systems with a charitable purpose crucially depend on extensive support of several actors. Collection quantities are substantially impacted by the commitment of partners like telecommunication providers, retailers, schools etc., which, on the one hand, are willing to take back mobile phones at their premises and thereby contribute to set up a widespread collection network. On the other hand, partners like the post, newspapers and others may distribute freepost envelopes, which are an especially convenient and, therefore, successful collection method, at little or no cost for the charitable programme. In short, successful charitable schemes like in Austria or New Zealand rely on the collective effort of several actors, which donate time and resources to yield high collection results and to raise money for a good cause.

The success of a collection scheme does, therefore, not depend on its category. Rather, as emphasised by MPPI (2009b), it is essential to ensure convenience to end users. Successful systems choose collection methods that provide a quick and easy-to-use way of handing in an old device. In practice, two main strategies have proven to be effective. First, systems provide drop-off boxes located in retail outlets at the point of sale and other highly frequented places such as supermarkets, public institutions, workplaces etc. It is crucial to establish a dense collection network so that drop-off points are easily accessible as exemplified by the Swiss system “Swico”. Second, high results can also be achieved by providing reply-paid envelopes, which represent a particularly convenient collection method. However, due to high costs associated with the reverse logistics of envelopes (TANSKANEN, 2013), they are currently only distributed by the Austrian “Ö3-Wundertüte” campaign, which relies on the support of several partners.

As PONCE-CUETO et al. (2011), PANAMBUNAN-FERSE & BREITER (2013) and TANSKANEN (2013) emphasise, citizen awareness is another prerequisite for high quantities of mobile phones recovered. Successful systems are able to communicate on a widespread level about the existence of the programme, the importance of recycling and the way used handsets can be delivered. As the cases of the charitable campaigns in Austria and New Zealand show, supporting a good cause by non-

monetary donations can be a strong incentive for people to hand in used mobile phones.

6. Conclusions

This thesis investigated mobile phone collection systems in Austria as well as on an international level in order to define factors of success and current trends and challenges.

As no consolidated statistics about end-of-life mobile phones in Austria could be identified, the time step method was applied. Based on sales data and the amount of devices in use, it could be estimated that approx. 2.7 million mobile phones become obsolete per year, which results in roughly 32 g/cap. Combined with a consumer survey by WIESER & TRÖGER (2015), it could be revealed that the majority of this amount, roughly 1.4 million units per year, is stored in households after use and one fifth of the waste potential or 550,000 units are directly diverted to reuse as end users sell or pass them on to family members and friends. It was estimated that official WEEE collection points and telecommunication providers only take back around 3 % of the amount of mobile phones put on the market, but on average 14 % of the annual sales quantity are donated to a good cause, which highlights the particular relevance of charitable organisations involved in the collection of mobile phones in Austria. For this reason, the most widespread and successful campaign "Ö3-Wundertüte" was analysed as a case study in terms of collection quantities and lifespan.

Based on a dataset containing more than 1.3 million reusable devices and 420 different models collected between 2011 and 2015 by the "Ö3-Wundertüte", it could be determined that roughly every second phone donated to the programme is fully functional. On average, 14 % of the total annual amount requires minor repairs and about one third is defective or obsolete and, thus, sorted out for recycling. The average total lifespan of reusable devices is 7.4 years, which indicates that a high share of old models released until the mid-2000s is still present in the input quantity. Considering that the average use phase is between two and three years (WIESER & TRÖGER, 2015; MURAKAMI et al., 2009), this supports the hypothesis that significant amounts of mobile phones are stockpiled in households and require several years to be disposed of by their owners.

In order to determine factors of success, 27 mobile phone collection programmes from 15 different countries were evaluated and classified into four groups according to BEIGL et al. (2012): WEEE collection system, branch system, commercial refurbishing, and charitable refurbishing. It could be shown that several different actors with varying objectives are involved in collecting mobile phones. While WEEE collection systems aim at the safe end-of-life treatment, i.e. recycling, the majority of branch systems as well as commercial and charitable programmes are orientated towards diverting functional handsets to reuse. This decision directly affects the systems' funding as revenues from reselling second-hand devices are higher than from material recycling alone. Consequently, schemes focusing on reuse are able to operate profitably or at least cost-covering and do not require additional funds in the form of, for example, fees from participating manufacturers and retailers. Typical reuse shares reported are around 60 % of the total collection result. In terms of collection quantities, the Swiss WEEE collection system for ICT, "Swico", turned out to achieve the highest results in relation to population size. On average, 68 units per 1,000 Swiss inhabitants are recovered per year. The Austrian charitable initiative "Ö3-Wundertüte" collects around 47 units per 1,000 inhabitants and comes in at the

second place. Among the schemes analysed that specifically focus on mobile phones, the Austrian campaign can, therefore, be regarded as the most successful. In line with literature sources, it could be confirmed that convenience to the end user by setting up a dense network of public drop-off points and providing free-post envelopes as well as creating widespread public awareness about the programme and the importance of handing in old devices are essential factors for high collection results. Nonetheless, collection rates of this waste stream are low compared to other types of WEEE. In Austria, an estimated 17 % of the average annual sales volume is separately collected, i.e. taken back by municipal collection points, telecommunication providers and charitable organisations. The overall collection rate for WEEE in Austria, however, is approx. 47 % (BMLFUW, 2017). Even in the case of the most successful scheme of “Swico”, only 17 % of the average amount placed on the Swiss market in the three preceding years was collected in 2016.

Data from the “Ö3-Wundertüte” showed that collected devices are frequently older than seven years and, thus, remain stored in households for several years until disposal. The consumers’ storage behaviour of old and unused mobile phones is among the main barriers for systems to increase collection rates. Possible approaches to reduce the hibernation period are, for example, introducing a deposit system on mobile phones similar to returnable bottles as suggested by SILVEIRA & CHANG (2010). Telecommunication providers and other mobile phone retailers could include information on drop-off points or free-post collection envelopes when a new model is purchased. Further research could analyse the motives for stockpiling and ways to reduce hibernating stocks. Also, investigating the time span used mobile phones are stored in households provides useful information for quantifying stockpiled amounts. Nevertheless, despite relatively low collection rates, mobile phone collection systems, which are frequently established on a voluntary basis, make an important contribution to diverting unused devices to reuse and recycling and to raising awareness about the safe disposal of WEEE.

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