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Global Circular Economy of Strategic Metals – the Best-of-two-Worlds Approach (Bo2W)

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Work package 2.1: Status Analysis Ghana

Work package 2.3: Generation WEEE and ELV

Work package 3.1: Status Analysis regarding collection, sorting and pre-treatment in Ghana

Authors

Andreas Manhart (Oeko-Institut)

Tobias Schleicher (Oeko-Institut)

Stefanie Degreif (Oeko-Institut)

Geschäftsstelle Freiburg
Postfach 17 71
79017 Freiburg
Hausadresse
Merzhauser Straße 173
79100 Freiburg
Telefon +49 761 45295-0

Büro Berlin
Schicklerstraße 5-7
10179 Berlin
Telefon +49 30 405085-0

Büro Darmstadt
Rheinstraße 95
64295 Darmstadt
Telefon +49 6151 8191-0

info@oeko.de
http://www.resourcefever.org

Bo2W project consortium

Oeko-Institut e.V.

Germany

Umicore

Belgium

Vacuumschmelze GmbH & Co. KG

Germany

Johnson Controls Power Solutions

Germany, United States

Centre for Environment and Development (CEDARE)

Egypt

City Waste Management Co. Ltd.

Ghana

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1. Work Package 2.1: Status Analysis Ghana

1.1. Ghana – facts and geographic overview

The West-African country of Ghana is sharing borders with Côte d'Ivoire, Burkina Faso and Togo. Ghana has a coastline of 539 km and covers an area of 238,533 km^2 roughly equalling the size of the United Kingdom (CIA 2013).

Ghana has a population of 25.5 million with an annual growth rate of 2.3 % (UN DESA 2011). 52.5 % of the population lives in cities. Accra, the country's capital is the largest town with 2.269 million inhabitants followed by Kumasi with 1.773 million.

Table 1 Selected figures and indicators for Ghana

Indicator	
Area	238,533 km2
Population	25.5 million
Population growth rate	+ 2.3 % per year
Urban population	52.5 % of total population
Capital & biggest city	Accra (2.269 million inhabitants in 2009)
GDP per capita	US$ 3,100
GDP-growth	+ 14.4 % (2011)
GDP – composition by sector	agriculture: 25.6 %; industry: 25.9 %; services: 48.5 %

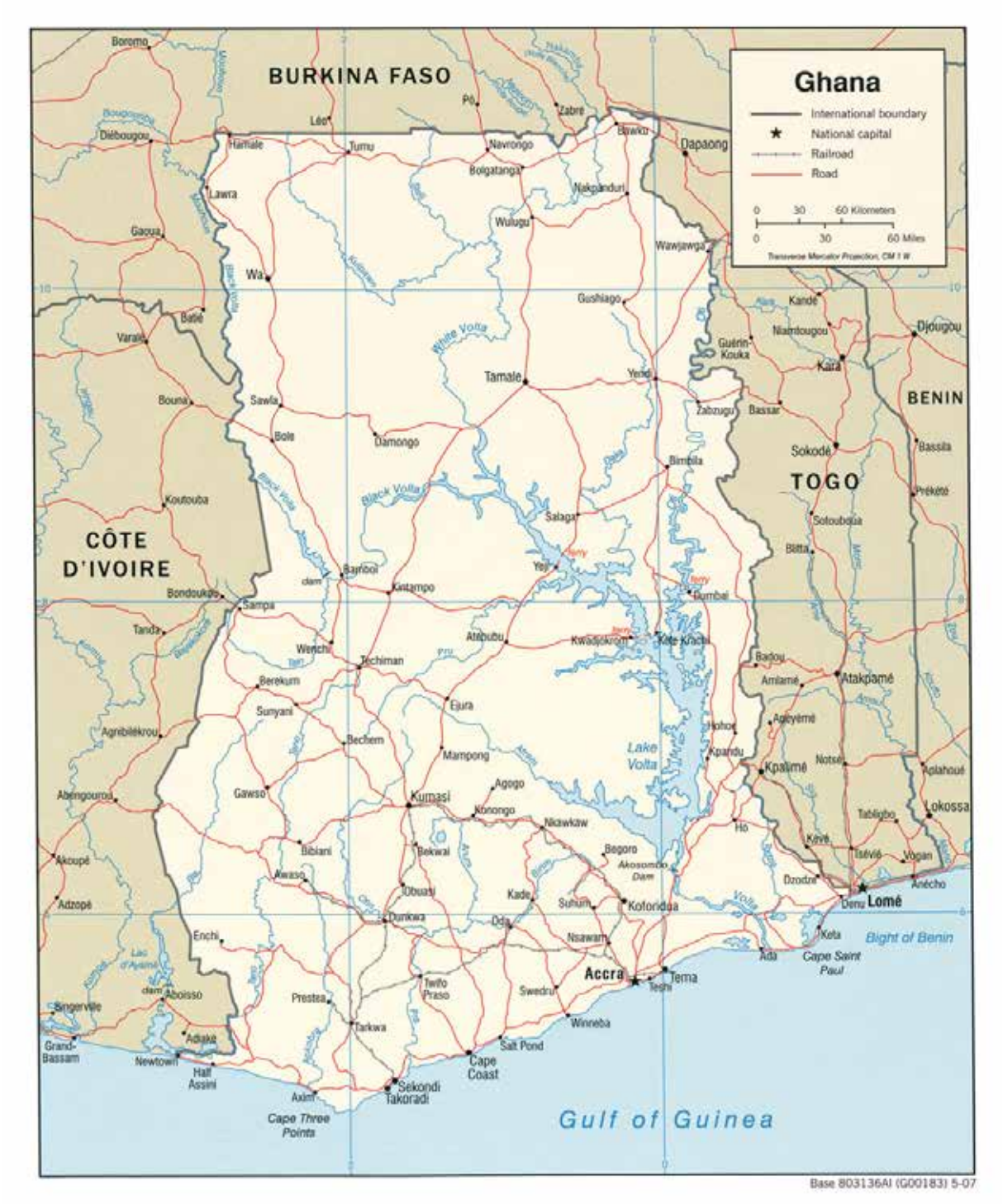
Source: CIA 2012

Ghana experienced rapid economic growth within the last years achieving rates of +4 % (2009), +8 % (2010) and +14.4 % (2011) making it one of Africa's fastest growing economies. Despite these developments, poverty is still a major problem with 30 % of the population living on less than US$ 1.25 per day.

While 56 % of the labour force is employed in agriculture, mining (particularly gold-mining) is the dominant industrial sector, followed by lumbering, light manufacturing, aluminium smelting, food processing, cement and small commercial ship building (CIA 2012).

Transport infrastructure is predominantly road-based but Ghana also has 947 km of railway lines, mainly connecting the main cities in the southern plains of the country (Accra, Tema, Kumasi, Awaso, Takoradi). The port city of Tema, which is located 30 km east of Accra is used for international sea trade.

Figure 1 Map of Ghana



Source: Washington, D.C.: Central Intelligence Agency, 2007

1.2. Development, infrastructure and ICT-penetration

As a background for the evaluation of the e-waste and car-waste situation, the development indicators shown in Table 2 and Table 3 are of interest.

Table 2 Selected development indicators for Ghana and other African countries

Indicator	Unit	Year of data	Ghana	Cote d'Ivoire	Togo	Benin	Nigeria	South Africa	Egypt
Human Development Index	rank	2011	135	170	162	167	156	123	113
Human Development Index	value	2011	0.541	0.400	0.435	0.427	0.459	0.619	0.644
Population below income poverty line	% of population with less than PPP $ 1.25 a day	2000-2009	30.0 %	23.8 &	38.7 %	47.3 %	64.4 %	17.4 %	2.0 %
Urban Population	% of total population	2011	52.5 %	51.3 %	44.1 %	42.5 %	50.5 %	62.2 %	43.5 %
Adult literacy rate	% of people aged 15 and above	2010	67 %	56 %	57 %[1]	42 %	61 %	n.d.	72 %
Youth literacy rate	% of people aged 15-24	2010	81 %	67 %	82 % [1]	55 %	72 %	n.d.	88 %
GNI	PPP $ billions	2011	45.2	34.5	6.4	14.7	372.8	542.0	504.8
GDP growth	%	2011	14.4 %	- 4.6 %	4.9 %	3.1 %	7.4 %	3.1 %	1.8 %
Population without electricity	%	2008	47.1 %	50.5 %	83.6 %	80.8 %	53.3 %	24.2 %	0.6 %

Source: UNDP 2010, UNDP 2011, World Bank 2013

Combined with additional information, they allow some first assertions regarding the use of electrical and electronic products within the country:

- 30 % of the country's population live on less than US$ 1.25 per day (Population below income poverty line). These people are economically not in the position to purchase any type of

[1] 2009 data.

expensive products such as electrical and electronic equipment (apart from devices such as torches), motorcycles or cars.

- 33.4 % of the adult population are illiterate (Adult literacy rate of 67%); this means that one third of the adult population are excluded from using information and communication technologies such as computers and mobile phones. Nevertheless, as youth literacy rate is above 80%, this share will gradually decline in the future.
- In 2008, almost half of the country's population (47.1 %) was not connected to an electricity supply (Population without electricity). Although this figure is likely to decrease over time, it is still an indication that a significant portion of the population cannot make use of many types of electric and electronic equipment such as refrigerators, computers or televisions. [2]
- According to official statistics from 2008 (Table 3), 73 % of the population lives within an area that is covered by a mobile phone network. Taking into account the rapid expansion of mobile phone coverage within the last years (Subscription rate per 100 inhabitants of 23,49 in 2006 and 84,74 in 2011), this figure indicates that mobile phone communication is possible in both urban and rural areas in Ghana.
- In 2011, mobile phone subscriptions reached almost 85 % in Ghana, which is a medium-high value for an African country.
- The figures from 2009 on motor vehicles and passenger cars reflect a relatively low motorisation rate. Nevertheless, road traffic increased significantly over the last years, which is also reflected in the rapidly increasing traffic congestion problems of Ghana's major cities.
- In 2010, 9.14 % of the Ghanaian households owned a computer. Nevertheless, the average annual growth rate of individuals' internet usage is quite high. The fixed (wired)-broadband subscription rate per 100 inhabitants grew from 0.06 in 2006 to 0.25 in 2011. This means that the general demand for computers and household internet access will increase. Presupposing further economic growth, this will almost certainly lead to an increased household penetration of computers and other ICT equipment.

[2] Nevertheless, households not connected to an electricity supply might still use battery- and/or solar-powered devices such as radios, torches or mobile phones.

Table 3 Selected ICT and transport indicators for Ghana and other African countries

Indicator	Unit	Year of data	Ghana	Cote d`Ivoire	Togo	Benin	Nigeria	South Africa	Egypt
Mobile-cellular tele-phone subscriptions	per 100 people	2011	84.78	86.42	50.45	85.33	58.58	126.83	101.08
Population covered by mobile phone network	%	2008	73 %	59 %	85 %	80 %	83 %	100 %	95 %
Internet users	%	2011	14.11	2.20	3.50	3.50	28.43	21.00	35.62
Fixed (wired) broad-band subscriptions	per 100 people	2011	0.25	0.08	0.08	0.04	0.13	1.80	2.21
Households with a computer	%	2010	9.14	1.76	3.70	2.48	8.00	18.33	34.00
Motor vehicles	per 1000 people	2009	30	n.d.	n.d.	n.d.	n.d.	162	45
Passenger cars	Per 1000 people	2009	18	n.d.	n.d.	n.d.	n.d.	110	33

Source: ITU 2012, UNDP 2010, World Bank 2011.

1.3. The current solid waste-management and recycling system

The per-capita generation of solid waste in Ghana is still well below those in industrialised countries. Generally, it is estimated that the per-capita generation lies at around 450 g per day (Meinel 2012), which results in an annual per-capita waste generation of 165 kg. Considering Ghana's population of 25.5 million, this accumulates to an annual solid waste generation of 4.2 million metric tonnes.

In urban centres there is a functioning household waste collection system, which is financed by the municipalities and tendered to private companies such as Zoomlion or Liberty Waste.

The collected household waste is disposed on landfills. There are currently only three sanitary landfills in Ghana[3], which altogether accommodate around 10% of the total solid waste generated in Ghana. Subsequently, the majority of the collected household waste is disposed of on non-sanitary waste dumps.

[3] These are located in Kumasi, Tamale and Tokoradi. Another sanitary landfill is currently under construction in Tema but not yet in service. All sanitary landfills have been installed with support of the World Bank.

Regarding material recovery from waste, the following initiatives are noteworthy:

- The company Zoomlion started the operation of a composting facility in the Accra region in 2012. The facility is fed with organic waste mechanically sorted out from the mass household waste stream. A source separation of organic waste is not established on a significant scale.
- There is one paper recycling facility in Tema offering a market for waste paper in Ghana. Thus, waste paper is often separately collected in households and businesses and sold to mostly informal collectors (see section 1.3). In addition, there is one recycling facility for cardboard in Accra. Its current operation status is unknown.
- There are four enterprises specialised in the recycling of post-consumer plastics. They are mostly supplied by an informal collection network providing PP, LDPE and HDPE for recycling. PET is not recycled in Ghana. Small PET-volumes (bottles) are exported.
- There is currently no glass recycling in Ghana. One glass recycling facility located in Aboso (Western Region) is out of service. A resumption of operation is currently considered and depends, amongst others, on the installation of new gas- and hydro-power-plants to supply electricity.
- City Waste Management is operating one facility for the recycling of sawdust from sawmills in Kaneshie. The saw dust is compressed to briquettes to be delivered to local bakeries. A second saw-dust recycling facility by another operator is currently in the planning phase and will be installed in Oda (Western Region). This facility is meant to produce briquettes for export to Germany.
- There are five secondary steel plants in Tema (Ferrous Steel, Tema Steel, Wahome Steel, Fine Steel, Western Steel). They buy scrap ferrous metal from Ghanaian sources and produce steel products mostly for the construction sector in Ghana.
- There is one lead smelter in Tema (Pagrik Ghana Ltd., part of the Indian Gravita Group) mainly focussing on the recycling of end-of-life starter batteries. Another lead smelter in Tema (Success Africa Ghana Ltd.) was closed several years ago because of its high environmental impacts. Together, these facilities had an annual capacity of 4,800 metric tonnes (PiD 2009).
- Shell maintains a take-back system for waste oil from its operations in Ghana. This take-back scheme is tied to the company's network of gas-stations and is not open to any other source of waste oil.
- City Waste Recycling is active in recycling of e-waste as well as exports of used lead-acid batteries. More information on these activities is provided in Chapter 3.

1.4. The relevance of the informal sector

Although solid waste collection is carried out in all urban agglomerations, informal waste collectors and recyclers (often referred to as 'scavengers') play an important role in Ghana. In particular, informal collectors take over the sorting of waste into recyclable fractions that are passed on to the established recycling industry in the country. This includes plastics, cardboard and paper as well as metal containing wastes (also see Chapter 3). Thus, informal waste collectors make use of the fact that source separation and separate collection is not practiced in Ghana.

Informal collectors operate at various waste collection points. While some collectors go from door to door to ask for recyclable waste (also see section 3.1), also employees of the regular solid waste collection sort out valuable materials from household waste.

Finally, waste pickers are active on waste disposal sites where they search the disposed waste for materials such as metals, plastics, paper and products for reuse.

1.5. The problem of waste imports

After the publication of the Greenpeace report *Poisoning the Poor* in 2008, international attention was drawn to the problem of e-waste imports into Ghana (Greenpeace 2008). Since that time, many journalists travelled to Ghana to visit the now famous Agbogbloshie Scrap Market and to write stories about the links between Western consumption patterns and its downstream impacts on developing countries. Most of these stories emphasised the fact that e-waste and used e-equipment are imported from countries such as the USA, the UK, Germany and the Netherlands in order to be cheaply recycled and disposed of in Agbogbloshie Scrap Market – with all the associated health and pollution problems. Furthermore, it is repeatedly stressed that these trade flows mark violations against the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, as non-functioning equipment (e-waste) was repeatedly found to be falsely labelled as used equipment for re-use.

While most of these reports are built on sound evidence and facts, they often fail to reflect the whole complex nature of the problem. For this reason, UNEP assigned several organisations[4] to collect comprehensive information on the trade flows and related management practices between the EU and five selected West-African countries (Liberia, Côte d'Ivoire, Ghana, Benin and Nigeria). Amongst others, this E-waste Africa Project revealed quite interesting results on the import stream using 2009 as a base year for this analyis:

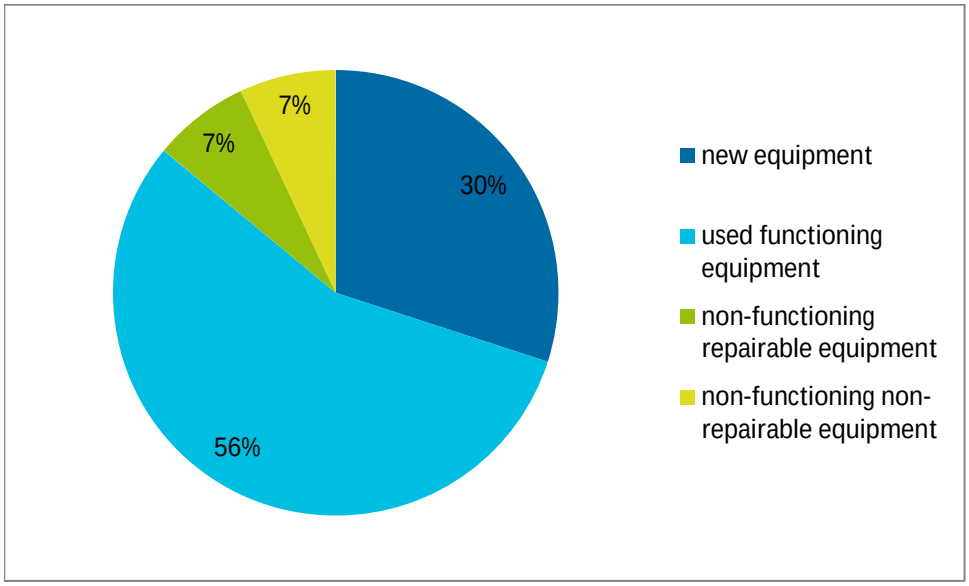
- In 2009, an estimated absolute amount of 215,000 t of electric and electronic equipment was imported into Ghana (Schluep et al. 2011). This figure takes into account registered imports of new and used equipment, as well as estimates on non-registered and illegal imports of used and end-of-life devices.
- Of all second hand equipment imported into Ghana, 85% came from EU countries (Amoyaw-Osei et al. 2011). While this is related to the fact that EU countries use the same voltage (230 V, 50 Hz) and TV-broadcasting technology as Ghana, the geographic proximity also plays a role.
- In 2009, used e-equipment (both functioning and non-functioning) made up 70 % of the total imports of electrical and electronic equipment into Ghana (see Figure 2).
- Household surveys confirmed that second-hand devices have a a relatively high market share in Ghana. According to Amoyaw-Osei et al. (2011), 51 % of private consumers opt for second-hand desktop computers in their purchasing decision. For monitors and notebook computers, these figures are 56 % and 38 %. Thus, it can be concluded that a considerable share of imported used equipment is primarily destined for re-use instead of recycling and/or disposal. Generally, in international trade, functioning used equipment is not considered as waste5 and does therefore not fall under the provisions of the Basel Convention.

[4] EMPA, Öko-Institut e.V., Basel Co-ordination Center for the African Region, IMPEL.

[5] One exemption is the trade of used cooling and freezing equipment that contains CFCs. These devices are banned from transboundary second-hand trade even if the devices are still functional.

- Nevertheless, 14 % of the imported e-equipment (equalling around 30,000 t) was not functioning in 2009. While half of this volume was reparable, the other half was clearly in a condition beyond repair (see Figure 2). These volumes (both, repairable and non-repairable items) are e-waste and fall under the provisions of the Basel Convention. As the competent authority in Ghana (EPA) did not receive any request for granting e-waste imports in 2009, these shipments constitute violations of the Basel Convention.
- Furthermore, a certain share of used functioning equipment was observed to be in quite bad condition and/or operating with outdated technology[6]. These devices mark a grey zone between legal imports of used equipment and illegal imports of non-functioning devices (Schluep 2012).

Figure 2 **Shares of new, used and end-of-life electrical and electronic equipment imported into Ghana in 2009 (weight based).**



Regarding the illegal imports, further analysis on the economic motivation behind this trade is needed. While some of this trade might be explained by the fact that some broken devices are shipped to be used as sources of spare parts for repair and refurbishing workshops, this cannot explain the total shipment volume of 30,000 t per year. While most journalists assume that the illegal e-waste trade is economically motivated by an evasion of compliance costs in industrialised countries, this driver can only be relevant for devices that in fact cause high compliance costs in formal recycling enterprises. While this is not the case for devices such as desktop PCs, which almost exclusively contain fractions of positive economic value (see Manhart et al. 2011a), CRT devices (TVs and monitors) and fridges contain materials and substances that require costly management practices in the EU[7]. Based on this observation, it can be assumed that that used and end-of-life fridges and CRTdevices represent the devices that make up the highest share of the illegal imports.

[6] This is sometimes observed with second-hand computers, which are functioning, but from their technical set-up not suitable to deal with modern software applications.

[7] CRTs: Leaded-glass, fluorescent powder, getter pastille. Fridges: CFCs and HFCs.

This consideration is supported by the observation that CRTmonitors are still declared as second-hand goods and imported into Ghana, despite the fact that the local second-hand monitor market is almost completely dominated by flat screens.

In the past, similar import patterns were observed for old fridges. Meanwhile, new legislation banning used fridges from being imported into Ghana together with strong enforcement[8] had impacts on this specific trade flow.

[8] In 2013, the Ghanaian custom authority confiscated more than 3,500 used and end-of-life fridges at Tema harbour.

2. Work Package 2.3: Generation of waste electrical and electronic equipment (WEEE) and end-of-life vehicles (ELV)

2.1. Mobile phones

In 2011, a total number of 21.166 million SIM cards were registered in Ghana (ITU 2012). The number of registered SIM cards can be used as a proxy to estimate the number of actively used mobile phones in a country. However, as it is likely that this proxy overestimates the number of actively used mobile phones, a correction factor of 0.9 is used due to:

- Prepaid SIM cards out of use
- SIM cards for data line (internet access only)
- Mobile phones that operate on dual SIM cards
- Temporary cellular line for foreign travellers

The case that a SIM card is possessed without a mobile phone is not considered.

Based on Ghana's socio-economic structure, characterized by low purchasing power in large parts of the population, it is estimated that the average active life time of a mobile phone is around six years. This comparably long life time is also in line with the observed fact that mobile phones are regularly repaired instead of being discarded.

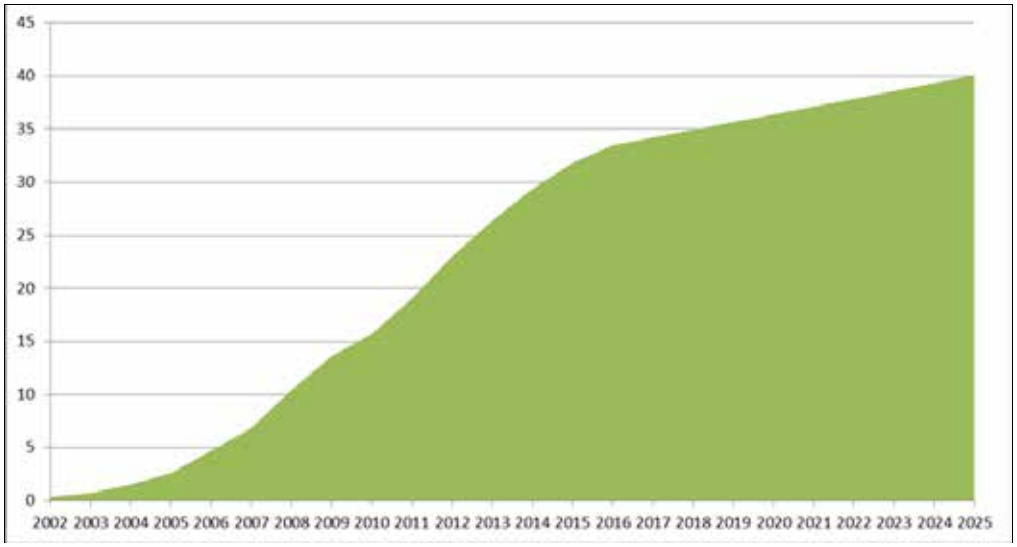
As Ghana lacks a comprehensive landline network, most telecommunication services are covered my mobile telephony. Over the past years, mobile telecommunication has revolutionized the daily life and communication opportunities of millions of people in Ghana. For the future, it can be assumed that the demand for mobile phones will further increases. Nevertheless, it is assumed that market saturation will be reached once the average penetration rate reaches 1.2 mobile phones per inhabitant[9]. In the following projection, this state is reached in 2016. After this, growth is assumed to be in line with the general population growth. This projected development should be considered a rough estimation Depending on Ghana's economic development, the corresponding saturation rate is likely to be reached between 2016 and 2021.

[9] 1.2 mobile phones per inhabitant is market saturation value obersved in many industrialised countries in cultural settings.

Figure 3 shows the number of mobile phones reaching their end-of-life in total. From the number of mobile phones in use (blue dotted line), market saturation can be expected from 2016 on (flattening of the curve towards a linear growth according to the population growth).

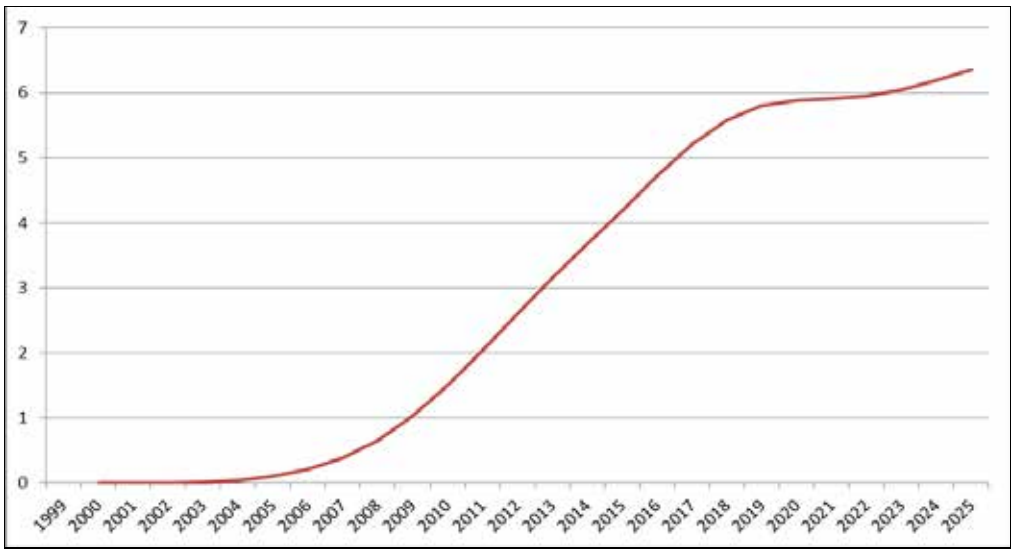
The detailed assumptions of the mobile phone calculations and projections are given in the Annex.

Figure 3 Projection of the number of mobile phones in use in Ghana from 2002 to 2025 [in millions]



Source: Projections by Oeko-Institut.

Figure 4 Projection of the number of EoL mobile phones per year in Ghana from 1999 to 2025 [in millions]

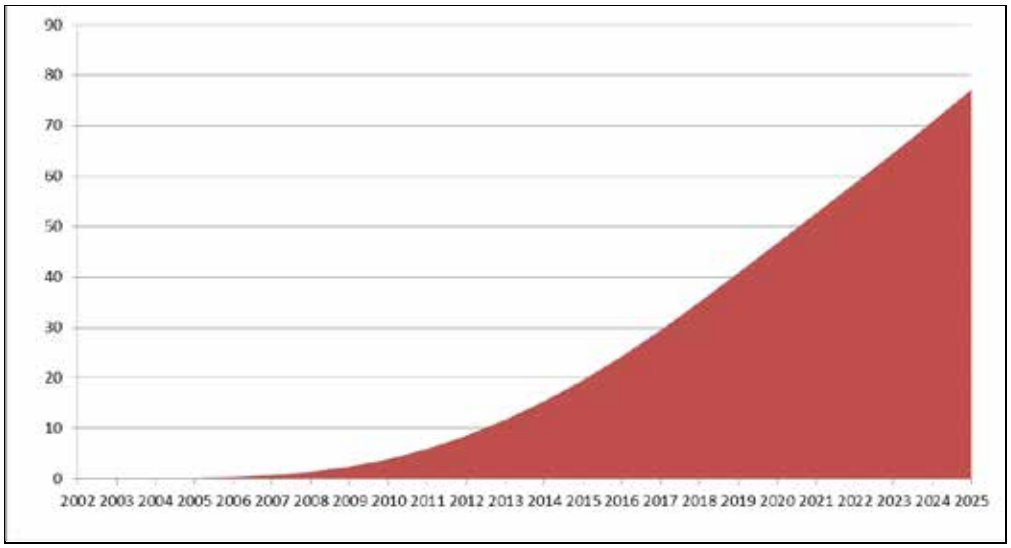


Source: Projections by Oeko-Institut.

Complementary to Figure 3, Figure 4 shows a projection of the number of mobile phones reaching end-of-life (EoL) annually (in mio.). Accordingly, around 3 million mobile phones reached their end-of-life in 2013 in Ghana. It is projected that until 2023 the number of mobile phones reaching end-of-life will strongly increase up to approx. 6 million devices per year.

Figure 5 provides the cumulative number of mobile phones reaching end-of-life from 2002 until 2025. It shows that in 2025, the cumulative number is projected to come close to the 80 million value. It should be stressed that this projection illustrates the upper limit for devices entering the waste stream. It is known that many consumers all over the world choose to store mobile phones not in use any more for several months or even years prior to disposal. Therefore, the actual number is likely to be significantly lower[10].

Figure 5 Projection of the cumulative number of EoL mobile phones in Ghana from 2002 to 2025 [in millions]



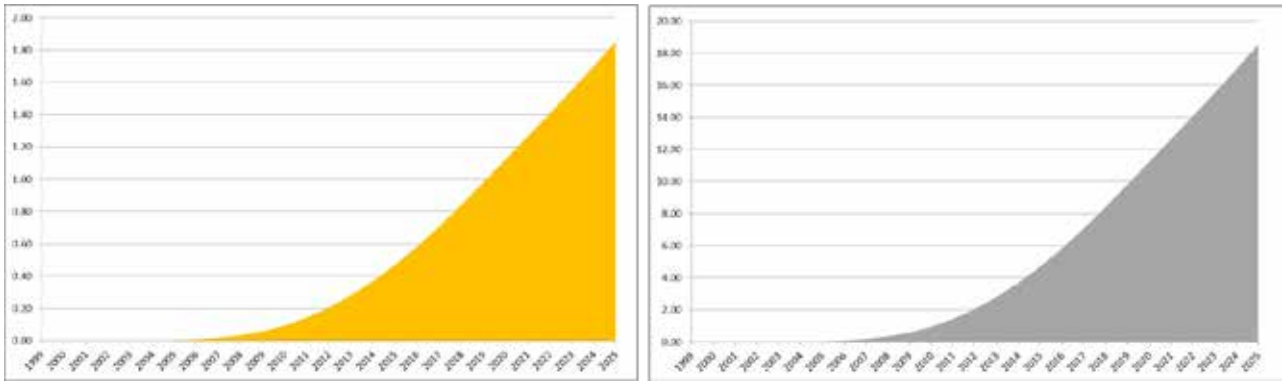
Source: Projections by Oeko-Institut.

Additionally, the cumulative amounts (potential) of gold and silver in end-of-life mobile phones are calculated and projected for the time period from 1999 to 2025. For this purpose, an average weight of mobile phones without batteries of 80 g is assumed. Furthermore, it is assumed that one end-of-life mobile phone contains an average of 0.24 grams of silver (~2180 ppm) and 0.024 grams of gold (~220 ppm).[11] The results of this projection are depicted in Figure 5, showing that in 2025 the cumulative amount of gold in mobiles phones is estimated at around 1.8 tonnes. Accordingly, the projected amount of silver is around 18 tonnes in 2025.

[10] This consumer habit is likely to be more pronounced in developing countries were electronic devices are often regarded as luxury goods. This situation was at least observed in Ethiopia, where (despite a rapidly rising market penetration of electronic equipment) the number of devices arriving in the waste stream is still negligible (Manhart et al. 2013). On the other side, convenient disposal options offered by the informal collection system in urban Ghana (see section 1.3) might also motivate consumers to dispose off mobile phones shortly after they have been taken out of use.

[11] It should be noted that the content of the different models of mobile phones could show different precious metals contents. The mentioned contents are based on the experience of the project partners.

Figure 6 **Projected cumulative potential of gold and silver in EoL mobile phones [tonnes]**



Source: Projections by Oeko-Institut.

Summarizing, Table 4 provides a summary of the estimations and projections of the mobile phones in use, the number and weights of end-of-life mobile phones and selected metals contained in these devices for the years 2010, 2012, 2015, 2020 and 2025.

Table 4 **Estimated and projected volumes of mobile phones* in use and end-of life in Ghana**

	2010	2012	2015	2020	2025
Mobile phones in use [number of devices]	15.69 million	23 million	31,82 million	36.4 million	40.1 million
EoL mobile phones [number of devices] per year	1.49 million	2.6 million	4.18 million	5.88 million	6.35 million
End-of-life mobile phones [weight excl. battery] per year	119 t	208 t	335 t	471 t	508 t
EoL mobile phones excluding battery; cumulative	313 t	685 t	1565 t	3739 t	6174 t
Gold in EoL mobile phones without battery, cumulative	0.09 t	0.21 t	0.47 t	1.12 t	1.85 t
Silver in EoL mobile phones without battery, cumulative	0.94 t	2.05 t	4.69 t	11.22 t	18.52 t
Palladium in EoL mobile phones without battery, cumulative	0.05 t	0.10 t	0.23 t	0.56 t	0.93 t

* all figures without chargers

Table 5 provides numbers and weights of EoL mobile phone batteries arising per year, respectively. Also, the associated amount of cobalt is described. The assumptions for the calculations are given in the Annex.

Table 5 Estimated and projected volumes of mobile phone batteries at end-of life in Ghana

	2010	2012	2015	2020	2025
EoL mobile phone batteries [number of devices] per year	5 million	6 million	10 million	10 million	10 million
EoL mobile phone batteries [weight] per year	139 t	190 t	294 t	350 t	384 t
EoL mobile phone batteries [weight] cumulative	421 t	775 t	1567 t	3247 t	5101 t
Cobalt in EoL mobile phone batteries [weight] cumulative	51 t	93 t	188 t	390 t	612 t

2.2. Desktop PCs & Notebooks

Amoyaw-Osei et al. (2011) estimated the number of installed computers (desktop PCs and notebooks) in 2009 in Ghana at 1.91 million, whereof 0.905 were used privately, 0.541 million in enterprises and 0.464 million in other institutions such as government offices and universities. 23.6 % of these computers are notebooks, 76.4 % desktop PCs (see Table 6).

Table 6 Number of installed desktop PCs and notebooks in Ghana in 2009

	Private households	Enterprises	Institutions	Total
Desktop PCs	622,000	471,000	367,000	1,460,000
Notebooks	283,000	70,000	97,000	450,000
Total	905,000	541,000	464,000	1,910,000

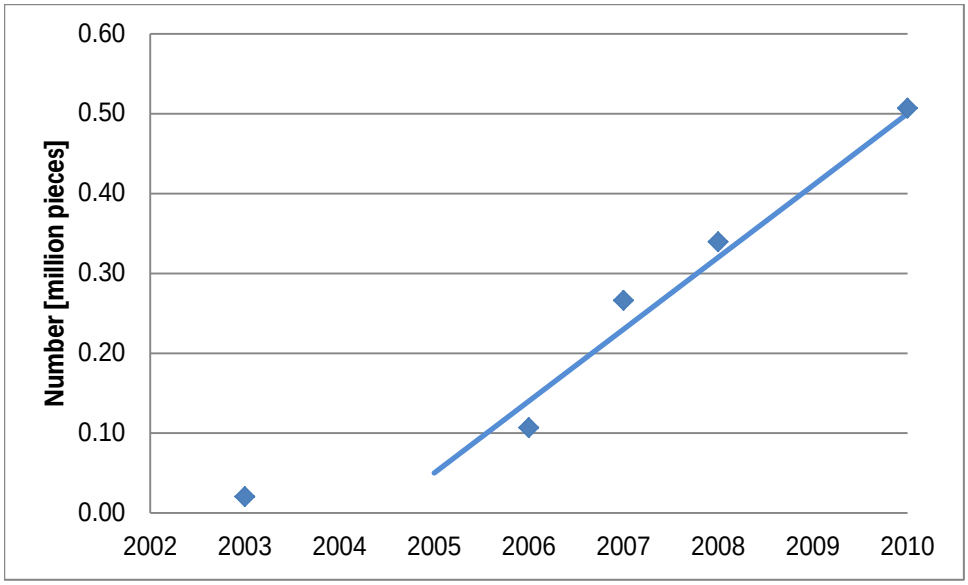
Source: Amoyaw-Osei et al. 2011

These figures correspond with the ITU-data on households equipped with at least one computer, which was 9.14 % in 2010 (ITU 2012). Considering the 5.545 million Ghanaian households in 2010, this indicates a minimum of 0.507 million privately used computers in 2010. As this figure does not account for the fact that some households own more than one computer, it systematically underestimates the total number of privately used computers in Ghana. Thus, the data provided by Amoyaw-Osei et al. (2011) are used as a baseline to calculate end-of-life numbers. Furthermore, it is assumed that the average desktop PC life time in Ghana is 4 years[12].

[12] While low purchasing power typically leads to above average use-times (> 6 years), another factor has to be considered in Ghana: The country receives a significant amount of second-hand imports serving the demand for low-cost ICT-equipment. Amoyaw-Osei et al. (2011) estimated the market-share of second-hand computers at 47% in 2009 with 51% for desktop PCs and 38% for notebooks. As second-hand devices typically have a limited remaining life time, a reduced average life time of four years for desktop PCs, notebooks and monitors (see section 2.3) appears adequate.

Regarding time series and growth rates, the only reliable figures available are the ITU-data on households equipped with at least one computer. These data suggest a somehow linear growth within the last years (see Figure 7).

Figure 7 Minimum number of computers in private households in Ghana



Assuming comparable growth developments in enterprises and other institutions, it can be estimated that the total number of computers in Ghana was 2.33 million in 2010. Furthermore, this data allows to estimate the number of computers (notebooks and desktops) in use in 2006 and 2008 (0.65 million and 1.49 million), which are likely to be in the same range as the number of end-of-life computers in 2010 and 2012.

To estimate the amount of notebooks in use and at their end-of-life, it is assumed that the market share of notebooks steadily increased, starting at 5 % in 2005.

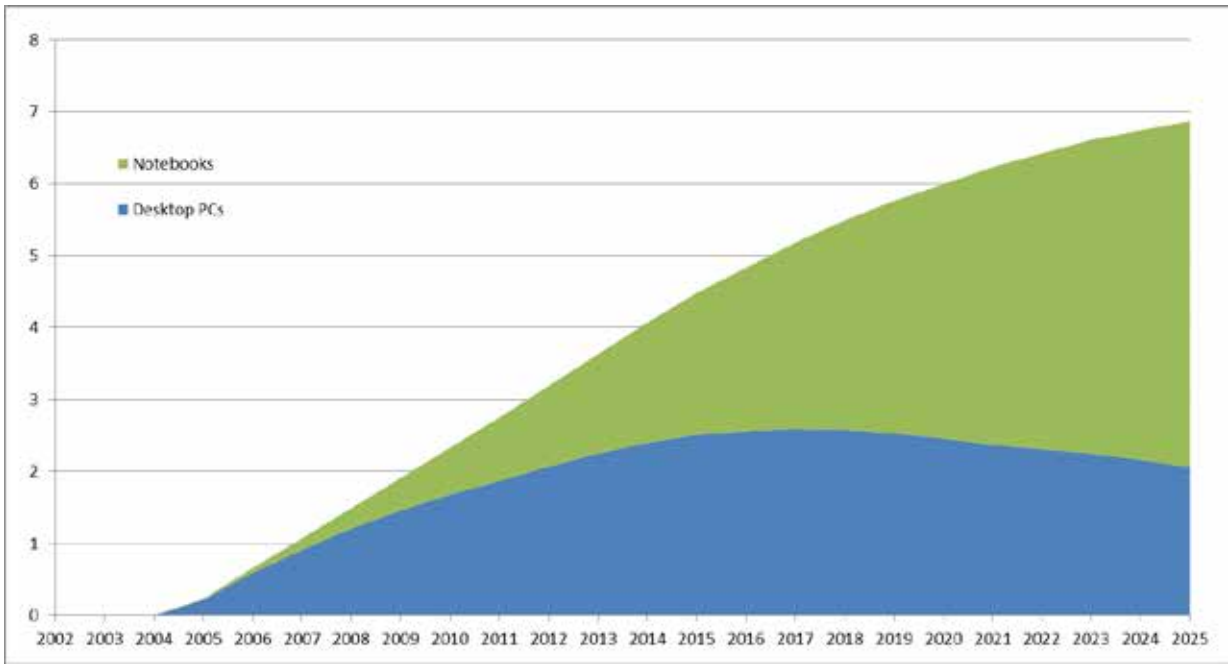
The future penetration of desktop PCs and notebooks is quite uncertain, as developments are driven by various highly variable factors such as technological trends in the ICT-sector, price levels as well as the economic developments in Ghana. As been observed in developed countries a trend towards tablet-PCs has recently been observed, it is likely that a comparable development will also affect Ghana in the near future. Nevertheless, the future development of the desktop PC and notebook use (installed number of devices) was modelled, based on the following assumptions:

- The linear growth will continue for some years and will then start to slow down gradually.
- Despite the rapidly growing economy, the share of households equipped with at least one computer will not reach the saturated levels which are seen in industrialised countries (75-90%)

within the next 20 years. This is due to the large disparities between the various income segments currently observed in Ghana, which are likely to further shape the socio-economic structure.

- In parallel to global developments, notebooks will experience an increasing market share in the future. According to this model, it will reach 70 % in 2025 for Ghana.
- According to the Ghana E-Waste Country Assessment (SCB e-Waste Africa Project 2011), the share of notebooks in offices (enterprises and institutions) was 37.11% in 2009, and 62.89 % in private households.
- The average life time of both desktop PCs and notebooks is assumed to be 4 years. This is due to the fact that a majority of the computers put on the market in Ghana are second-hand devices. The life time is modelled according to a normal deviation (Gaussian) with a standard deviation of 1.25 years.
- It is assumed that desktop PCs and notebooks will continue to be the dominant hardware computing systems in the next decades – despite the fact that client-server systems, cloud computing and tablet PCs are gaining increasing importance worldwide. This decision was taken in order to reduce modelling complexity.[13]

Figure 8 Projection of the number of desktop PCs and Notebooks in use in Ghana [in millions]



Source: Projections by Oeko-Institut.

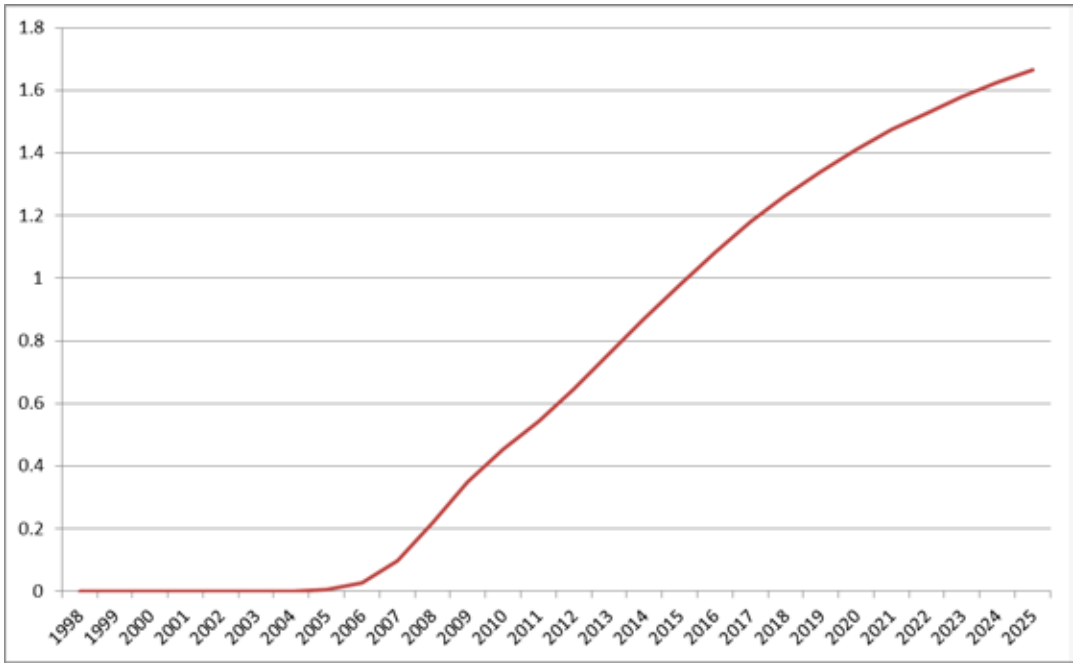
Following the above stated assumptions, Figure 8 shows the results for the projections of the number of computers (desktops and notebooks) in use in Ghana. It shows that the use of desktop PCs is expected to peak around 2017 since it is assumed that they will be increasingly substituted

[13] The aim of this modelling exercise is to estimate the end-of-life volumes and calculate the corresponding resource potential from computing systems in Ghana. As thin clients and tablet PCs have a comparable material composition as desktop PCs and notebooks, these technological trends are – from a material perspective – partly covered in the modelling exercise.

by notebooks. Also, the overall growth of the number of computers in use is projected to come close to 7 million devices in 2025.

In addition to the total number of computers in use illustarted in Figure 9, the number of devices reaching end-of-life is illustrated in Figure 9. It shows a steady increase in the annual number of EoL computers from around 0.4 million in 2010 to an estimated 1.7 million devices in 2025.

Figure 9 **Projection of the number of EoL computers (desktop PCs and notebooks) per year in Ghana from 1998 to 2025 [in millions]**

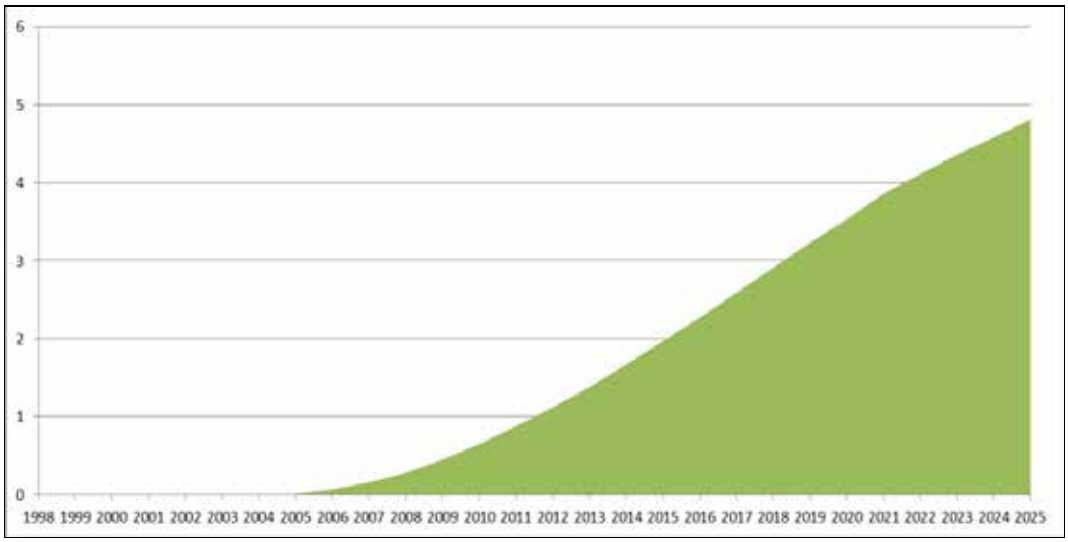


Source: Projections by Oeko-Institut.

2.2.1. Notebooks

Figure 10 shows the steady increase of notebooks in use in Ghana from 1998 until 2025. It is projected that in 2025, the number of notebooks in use will come close to 5 million devices.

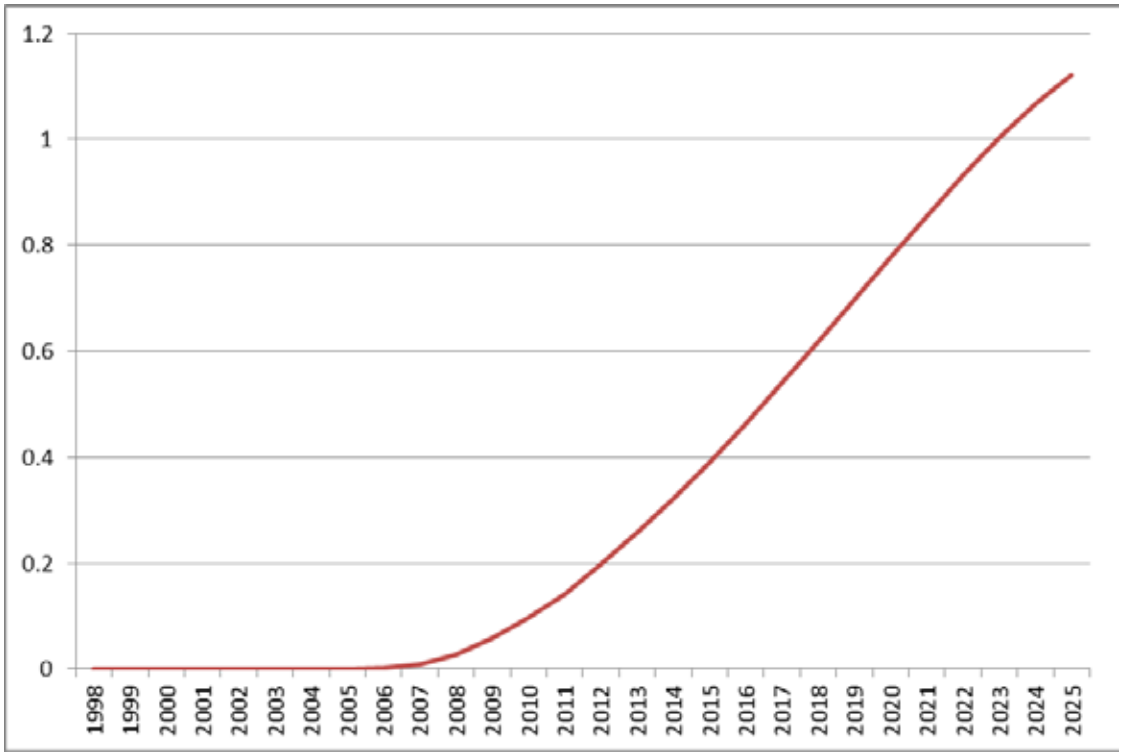
Figure 10 Projection of the number of notebooks in use in Ghana from 2002 to 2025 [in millions]



Source: Projections by Oeko-Institut.

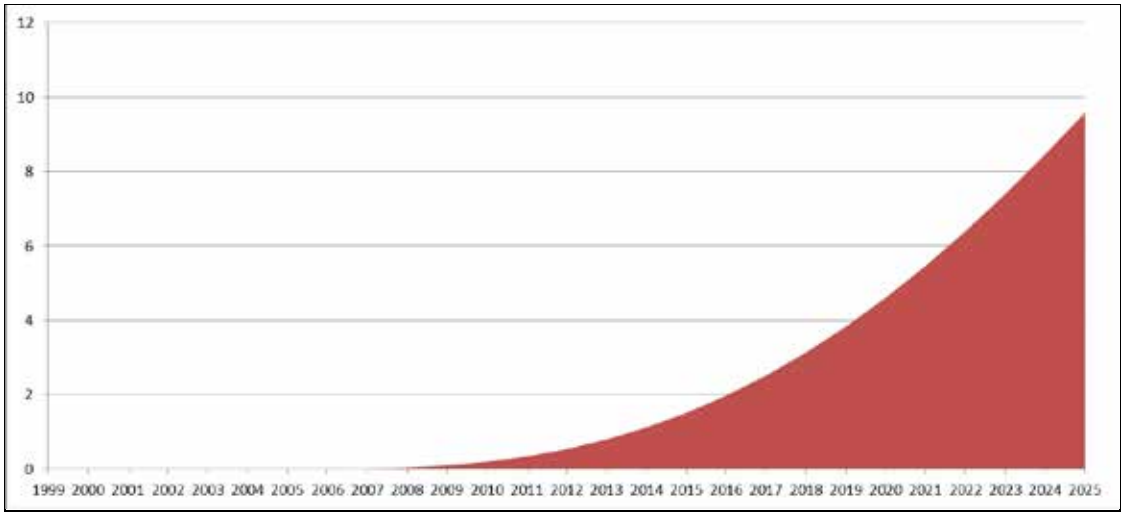
Figure 11 shows that significant amount s of EOL notebooks started to arise from 2007/08 onwards and are predicted to reach around 200,000 in 2012. Accordingly, Figure 12 provides the cumulative estimations for EoL notebooks for the years 2007 to 2025. The cumulative number of EoL notebooks is projected to come close to 10 million devices in 2025.

Figure 11 **Projection of the number of EoL notebooks per year in Ghana from 2002 to 2025 [in millions]**



Source: Projections by Oeko-Institut.

Figure 12 **Projection of the cumulative number of EoL notebooks in Ghana from 2002 to 2025 [in millions]**



Source: Projections by Oeko-Institut.

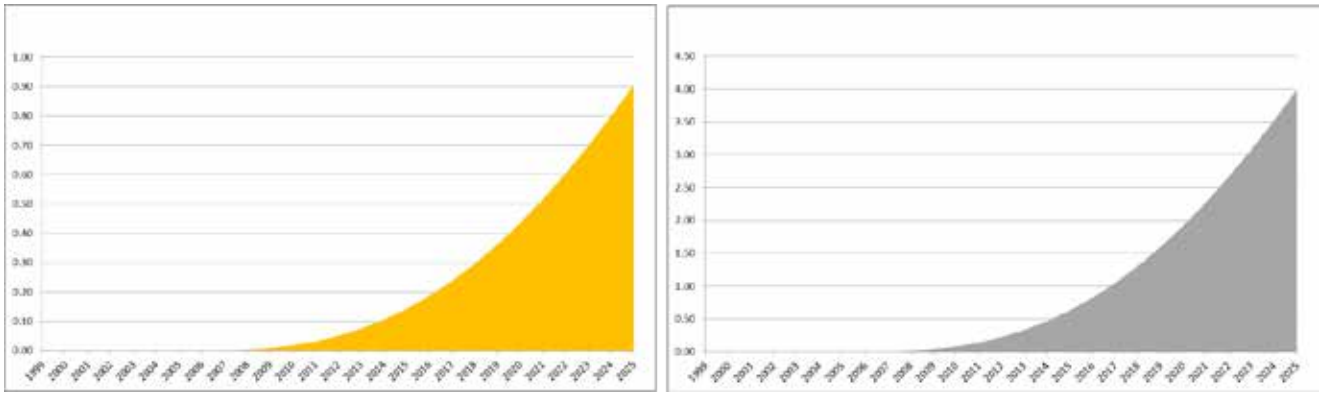
Based on these cumulative quantitative estimations, the cumulative amount of gold and silver contained in these devices is projected until 2015. It is assumed that

- One notebook has a weight of 2.5 kg
- Gold content of one notebook is 0.094 g, which is composed as follows (Source: Umicore):
  - 180 ppm in motherboard and small PWBs
  - 750 ppm in memory cards
  - 400 ppm in HDD PWB
  - 200 ppm in PWB for optical drive
  - 490 ppm display PCB
- Silver content of a notebook is 0.416 g, which is composed as follows (Source: Umicore):
  - 800 ppm in motherboard and small PWB
  - 1650 ppm in memory cards
  - 2600 ppm in HDD PWB
  - 2200 ppm in PWB for optical drive
  - 1300 ppm display PWB

Figure 13 shows that in 2025 0.9 tonnes of gold have accumulated in the EoL notebooks that have been in use in Ghana. Accordingly, around 4 tonnes of silver have accumulates until 2025.

Table 7 provides a summary of the data for the years 2010, 2012, 2015, 2020 and 2025 including the absolute numbers for notebooks. Besides, the amount of gold and silver (potential) illustrated in Figure 14, the amount of palladium and plastics are estimated based on the absolute cumulative weights of EoL notebooks arising until 2025. Detailed assumptions for the calculation are listed in Annex.

Figure 13 Projected cumulative potential of gold and silver in EoL notebooks [tonnes]



Source: Projections by Oeko-Institut.

Table 7 Estimated and projected volumes of notebooks in use and at end-of-life in Ghana

	2010	2012	2015	2020	2025
Notebooks in use [number of devices]	0.65 million	1.12 million	1.97 million	3.53 million	4.91 million
EoL notebooks [number of devices] per year	0.10 million	0.20 million	0.39 million	0.78 million	1.12 million
EoL notebooks [weight without peripherals] per year	241 t	495 t	976 t	1943 t	2806 t
EoL notebooks [weight without peripherals] cumulative	483 t	1,334 t	3,766 t	11,512 t	23,967 t
Gold in EoL-notebooks cumulative	0.02 t	0.05 t	0.14 t	0.43 t	0.90 t
Silver in EoL- notebooks cumulative	0.08 t	0.22 t	0.63 t	1.92 t	3.99 t
Palladium in EoL- notebooks cumulative[14]	0.01 t	0.02 t	0.06 t	0.18 t	0.37 t
Plastics in EoL notebooks cumulative[15]	136.22 t	376. 27 t	1061.95 t	3246.49 t	6758.60 t

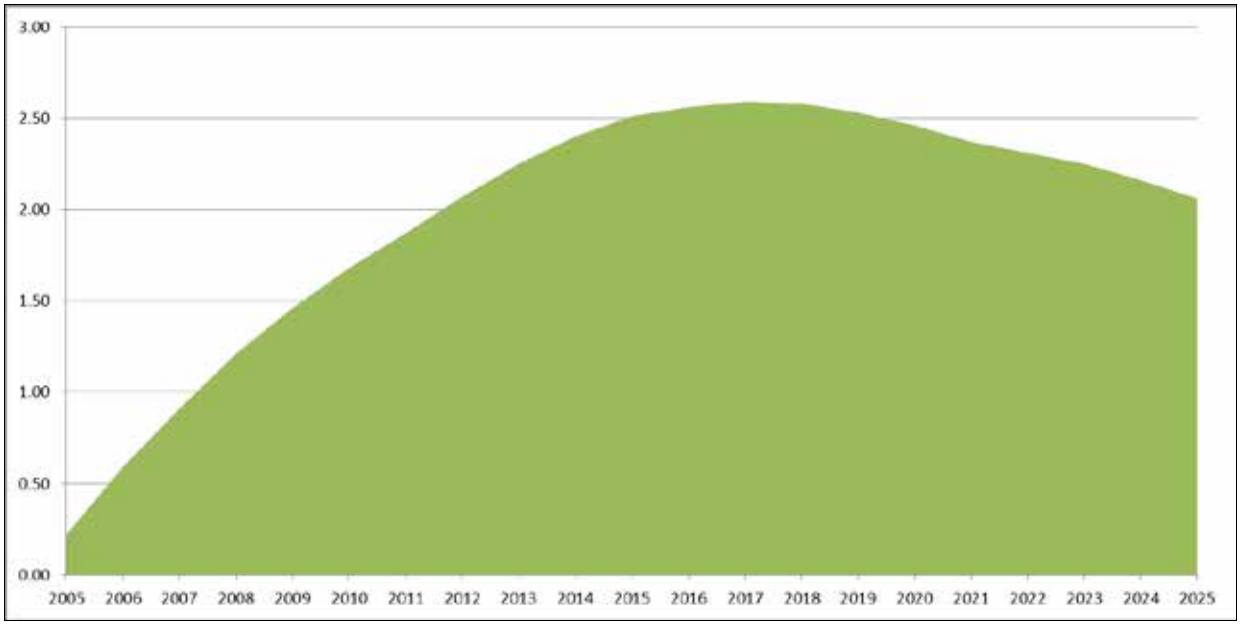
[14] The palladium content of a notbeook is based on UMICORE data (0.099 g of palladium per unit weighing 2.5 kg).

[15] According to UMICORE data (End-of-Life List) a 3 kg notebook contains 846 g of plastics. The plastic content has been calculated for a 2.5kg notebook assuming the same percentage of plastic. ,resulting in a figure of 705g plastics per unit.

2.2.2. Desktop PCs

Figure 14 shows that the number of desktop PCs in use has been increasing very fast since 2005. However, it is assumed that this number will peak between 2015 and 2018 at a level of above 2.5 million devices.

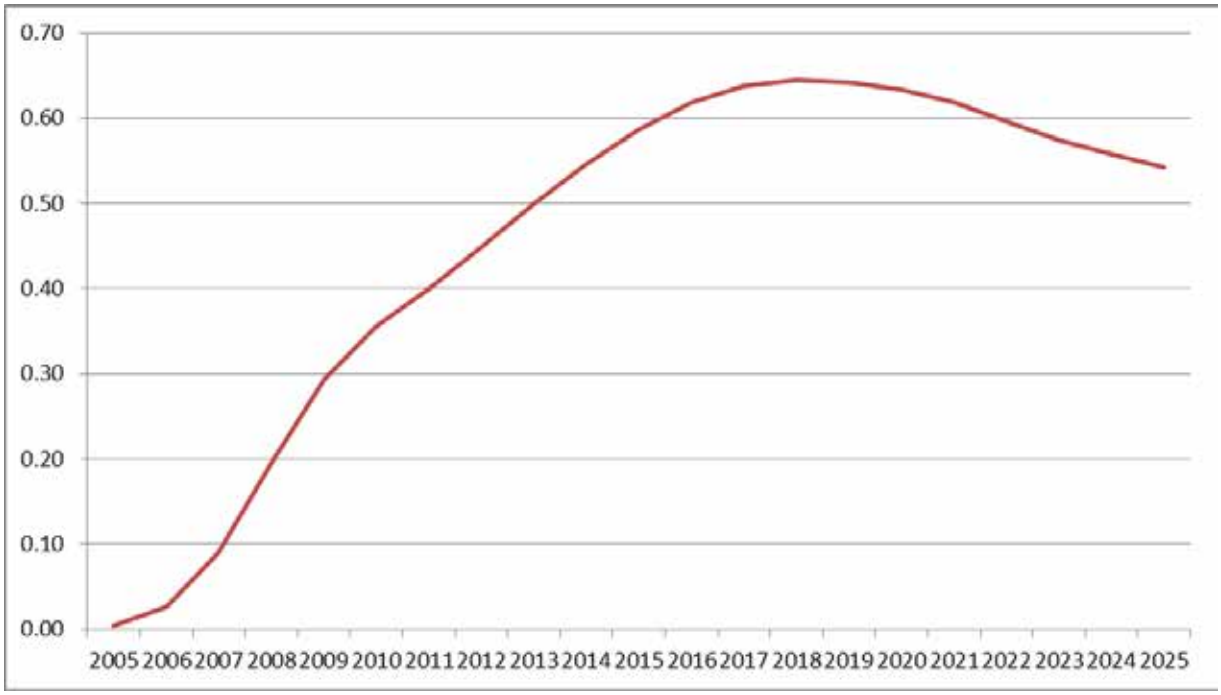
Figure 14 Projection of the number of desktop PCs in use in Ghana from 2002 to 2025 [in millions]



Source: Projections by Oeko-Institut.

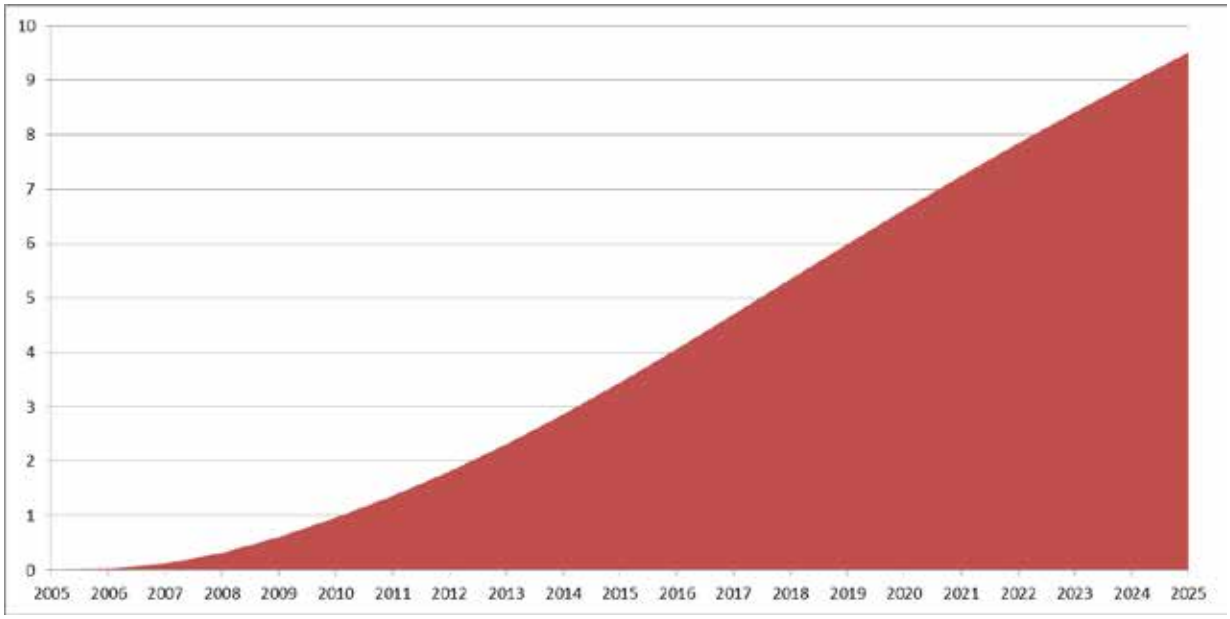
According to the above stated assumptions (see section 2.2), the annual number of desktop PCs reaching end-of-life (EoL) in Ghana is estimated and projected until 2025. Figure 15 illustrates a steep growth in the number of EoL desktop PCs between 2005 and 2018 peaking at around 0.64 million in approx. 2018. Subsequently, the annual number of EoL desktop PCs is declining to around 0.54 million per year in 2025. This translates into cumulative numbers as illustrated in Figure 16. The estimations show that the cumulative number of EoL desktop PCs from use in Ghana reaches around 9.5 million in 2025.

Figure 15 **Projection of the number of EoL desktop PCs per year in Ghana from 2002 to 2025 [in millions]**



Source: Projections by Oeko-Institut.

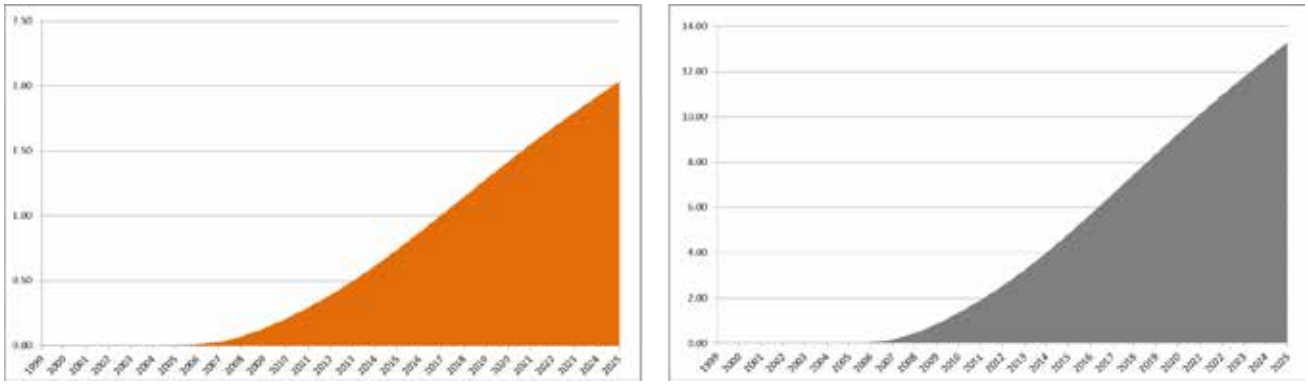
Figure 16 **Projection of the cumulative number of EoL desktop PCs in Ghana from 2002 to 2025 [in millions]**



Source: Projections by Oeko-Institut.

Assuming an average weight of 8 kg per desktop PC, an average gold content of 0.214 g per unit and an average silver content of 1.398 g per unit (Gmünder 2007 adjusted for weight), the cumulative amount of gold and silver in desktop PCs from use in Ghana was estimated for the year 2025. Figure 17 shows that the total amount of gold in desktop PCs will reach around 2 tonnes – while the figure for silver it will reach 13 tonnes in 2025.

Figure 17 Projected cumulative potential of gold and silver in EoL desktops [tonnes]



Source: Projections by Oeko-Institut.

Table 8 provides a summary of the estimated data for the years 2010, 2012, 2015, 2020 and 2025. Based on the cumulative weight of desktop PCs, the cumulative amount (potential) of gold and silver are derived (Figure 17). Furthermore, the volumes for palladium and plastics are estimated.

Table 8 Estimated and projected volumes of desktop PCs in use and at end-of-life in Ghana

	2010	2012	2015	2020	2025
Desktop PCs in use [number of devices]	1.68 million	2.07 million	2.51 million	2.46 million	2.06 million
EoL desktop PCs [number of devices] per year	0.36 million	0.45 million	0.59 million	0.63 million	0.54 million
EoL desktop PCs [weight without monitor & peripherals] per year	2,846 t	3,587 t	4,699 t	5,074 t	4,340 t
EoL desktop PCs [weight without monitor & peripherals] cumulative	7,713 t	14,502 t	27,570	52,982 t	76,090 t
Gold in EoL- desktops cumulative	0.21 t	0.39 t	0.74 t	1.41 t	2.03 t
Silver in EoL- desktops cumulative	1.35 t	2.53 t	4.82 t	9.26 t	13.30 t
Palladium in EoL- desktops cumulative	0.10 t	0.18 t	0.34 t	0.65 t	0.94 t
Plastics in EoL- desktops cumulative	1,654 t	2,483 t	3,882 t	6,108 t	7,974 t

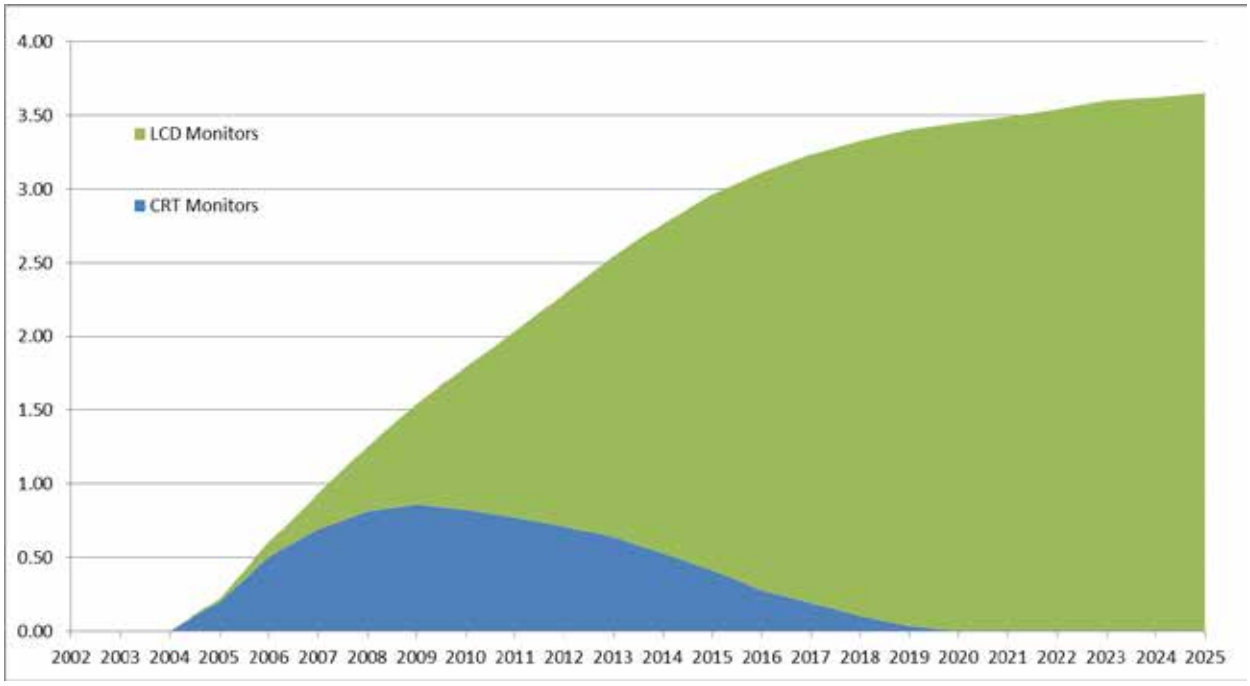
2.3. Cathode Ray Tube (CRT) & Liquid Crystal Display (LCD) Monitors

It is assumed that each desktop PC is equipped with one monitor with a comparable life time of four years. Furthermore, it is assumed that 20% of all notebooks are used with additional stand-alone monitors (e.g. via docking station). As notebooks will gain increasing importance also in office use, it is assumed that this share will rise to 33% until 2025.

Regarding the split between CRT monitors and LCD monitors, Amoyaw-Osei et al. (2011) provide figures indicating that 56% of all privately used monitors were CRTs in 2009. Considering the constant shift towards LCD technology, it is further assumed that the last (second-hand) CRT monitors will enter the Ghanaian market around 2016, which will lead a full phase out of CRT monitors until around 2019/2020[16] (see Figure 18).

[16] Here it has to be considered that Ghana is a major second-hand market for EEE from Europe and other industrialised countries. Thus, CRT phase-out in Ghana will have a time lag of several years compared to the European market.

Figure 18 Projection of the number of LCD and CRT monitors in use in Ghana [in millions]



Source: Projections by Oeko-Institut.

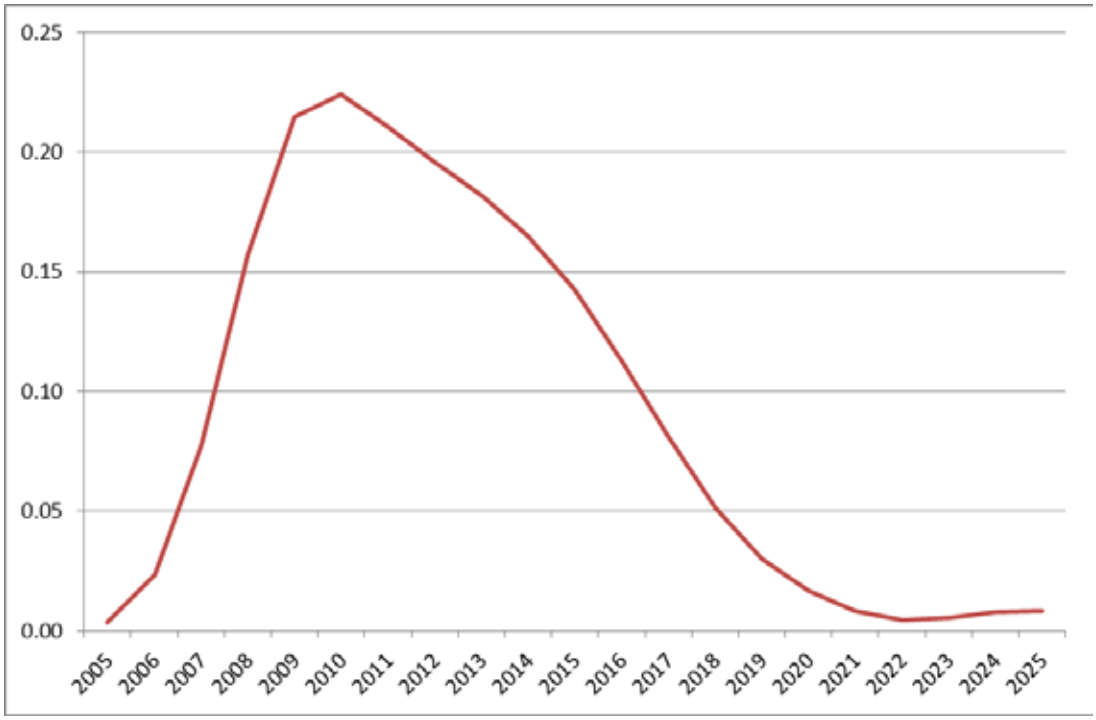
Figure 19 illustrates the steady growth of the number of monitors (CRT & LCD) in use in Ghana. As the share of CRT monitors declines constantly after its peak in 2009, it is estimated that after 2020 only LCD will be in use, reaching around 3.65 million devices in 2025.

2.3.1. CRT monitors

Under the assumption of an average residual lifetime of 4 years after entering the market in Ghana, a scenario for the number of end-of-life CRT monitors is calculated in the following. Thereby, the life time follows a normal distribution around the mean with a standard deviation of 1.25 years. Additionally, the weight of one CRT monitor is assumed to be 14.23 kg (Wecycling 2011, Bleher 2013).

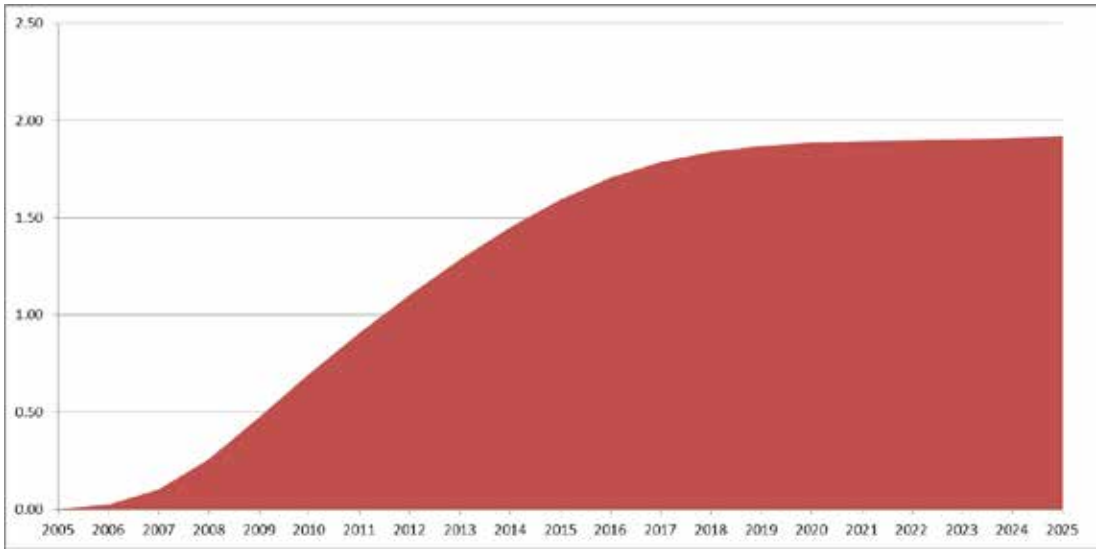
Figure 19 shows that the number of EoL CRT monitors per year peaked in 2010 with an annual volume of 220,000 pieces. After 2021 e-waste generation by CRT monitors is estimated to be mostly phased out. The annual number translates into a cumulative number as illustrated in Figure 20, showing again that the cumulative number of EoL CRT monitors will remain rather constant after 2020.

Figure 19 **Projection of the number of EoL CRT monitors per year in Ghana [in millions]**



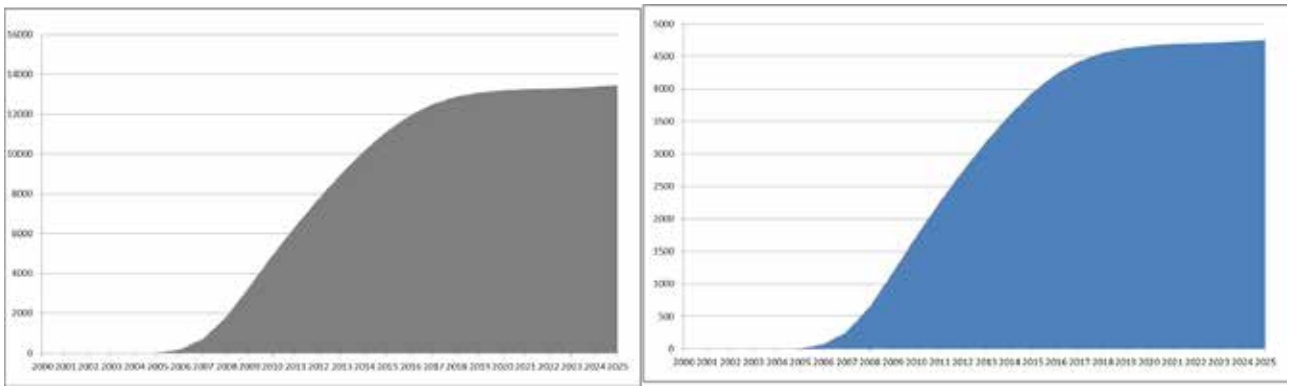
Source: Projections by Oeko-Institut.

Figure 20 **Projection of the cumulative number of EoL CRT monitors [in millions]**



Source: Projections by Oeko-Institut.

Figure 21 Projected cumulative potential of CRT tubes and plastics in CRT monitors [tonnes]



Source: Projections by Oeko-Institut.

For CRT monitors, two recycling fractions attributed with a negative intrinsic value are of special interest. Firstly, CRT lead-glass is in the focus, as improper disposal leads to significant lead pollution. Secondly, plastics are in the focus. It is assumed that each EoL CRT monitor contains around 2.47 kg of plastics and 7 kg of CRT tubes. Figure 21 illustrates that the cumulative potential of CRT tubes is estimated to be 13,440 tonnes; the cumulative potential of plastics from EoL CRT monitors is 4,753 tonnes, in 2025 respectively.

Table 9 Estimated and projected volumes of CRT monitors in use and at end-of-life in Ghana

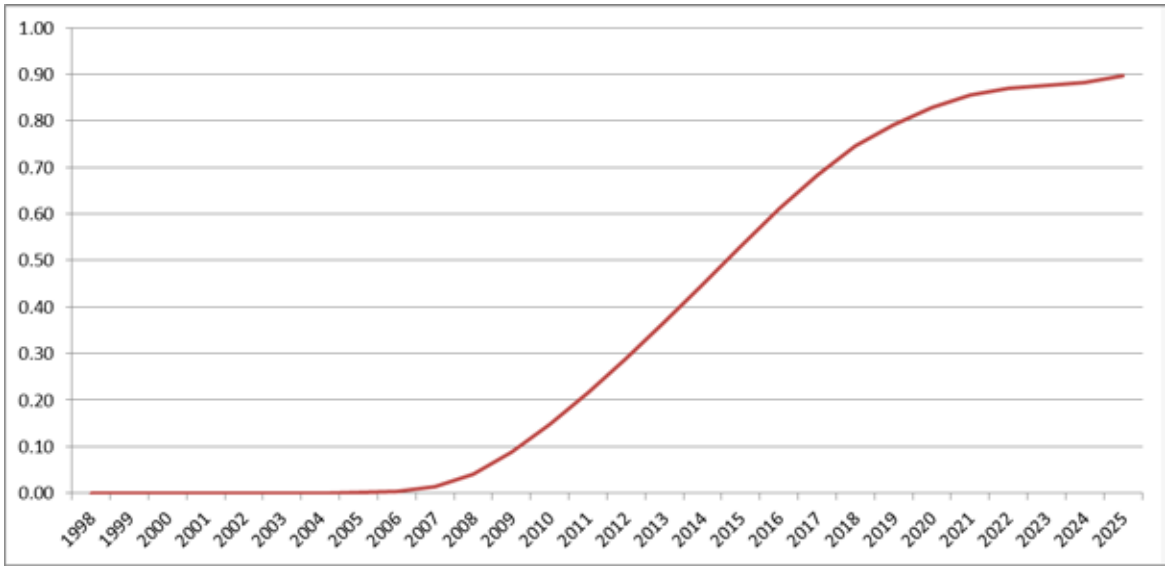
	2010	2012	2015	2020	2025
CRT monitors in use [number of devices]	0.83 million	0.71 million	0.41 million	-	-
EoL CRT monitors [number of devices] per year	0.22 million	0.20 million	0.05 million	0.02 million	0.01 million
EoL CRT monitors [weight] per year	3,190 t	2,782 t	2,024 t	238 t	114 t
EoL CRT monitors [weight], cumulative	9,957 t	15,728 t	22,685 t	26,839 t	27,318 t
Plastic potential in EoL CRT monitors, cumulative [weight]	1,732 t	2,737 t	3,947 t	4,670 t	4,753 t
CRT tube potential in EoL CRT monitors, cumulative [weight]	4,899 t	7,738 t	11,161 t	13,205 t	13,440 t

2.3.2. LCD monitors

Under the same assumption as for CRT monitors regarding mean residual lifetime (4 years) and standard deviation (1.25 years) in a Gaussian normal distribution, in the following, the annual number of LCD monitors reaching end-of-life is projected. Figure 22 illustrates that before 2007

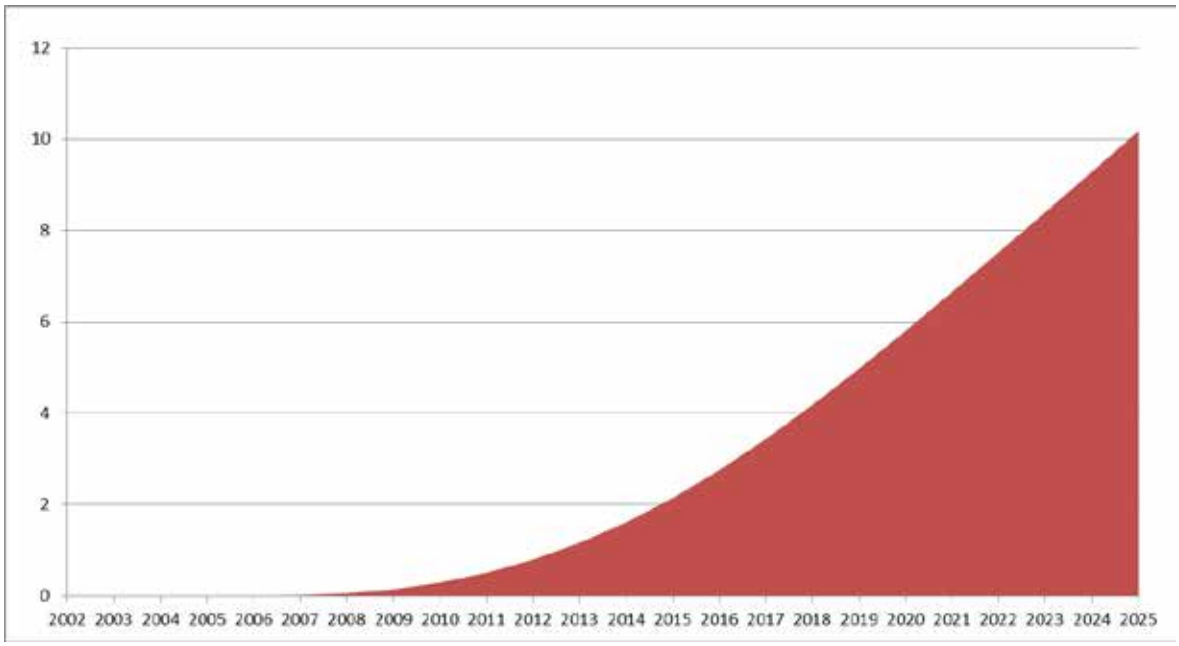
EoL-LCD monitors were not relevant in Ghana. After 2007, a constant growth of EoL LCD monitors is projected to lead to 0.9 million pieces per year in 2025. The annual number of EoL LCD monitors sum up to cumulative number of EoL devices as illustrated in Figure 23. Accordingly, the cumulated number of EoL-LCD monitors is projected to reach 10.2 million devices in 2025.

Figure 22 Projection of the number of EoL LCD monitors per year in Ghana [in millions]



Source: Projections by Oeko-Institut.

Figure 23 Projection of the cumulative number of EoL LCD monitors in Ghana [in millions]



Source: Projections by Oeko-Institut.

Table 10 provides the summary of estimations and projections of LCD monitors in use in 2010, 2012, 2015, 2020 and 2025. For the calculation of the cumulated weight of EoL-LCD monitors, a weight of 4.7 kg was assumed (Amoyaw-Osei et al. 2011).

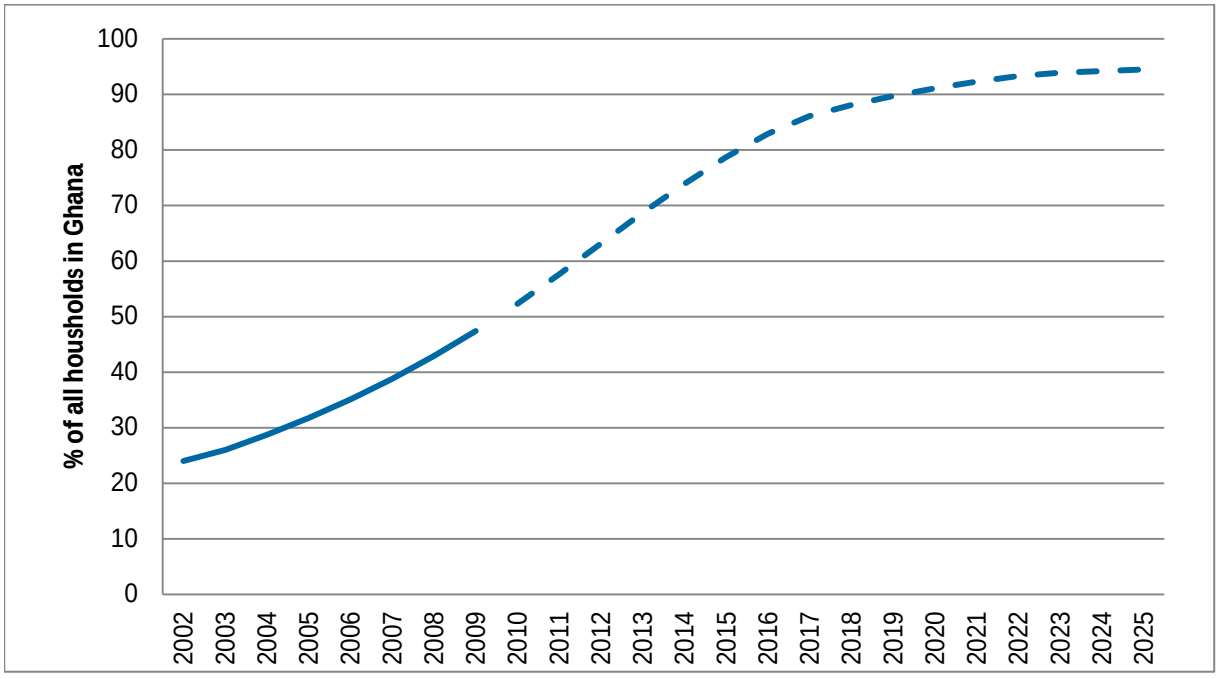
Table 10 Estimated and projected volumes of LCD monitors in use and at end-of-life in Ghana

	2010	2012	2015	2020	2025
LCD monitors in use [number of devices]	0.97 million	1.58 million	2.55 million	3.45 million	3.65 million
EoL LCD monitors [number of devices] per year	0.15 million	0.29 million	0.53 million	0.83 million	0.90 million
EoL LCD monitors [number of devices] cumulative	0.29 million	0.80 million	2.15 million	5.81 million	10.19 million
EoL LCD monitors [weight] cumulative	1,384 t	3, 759 t	10, 084 t	27, 293 t	47,874 t

2.4. TVs

According to ITU-data (ITU 2012), in 2009 47.4 % of the households or 2.575 million households in Ghana were equipped with at least one TV. The time series generated with ITU-data (Figure 24) shows a growing ownership of TVs which is likely to continue in the future.

Figure 24 Share of Ghanaian households owing at least one TV.



Source: Projections by Oeko-Institut.

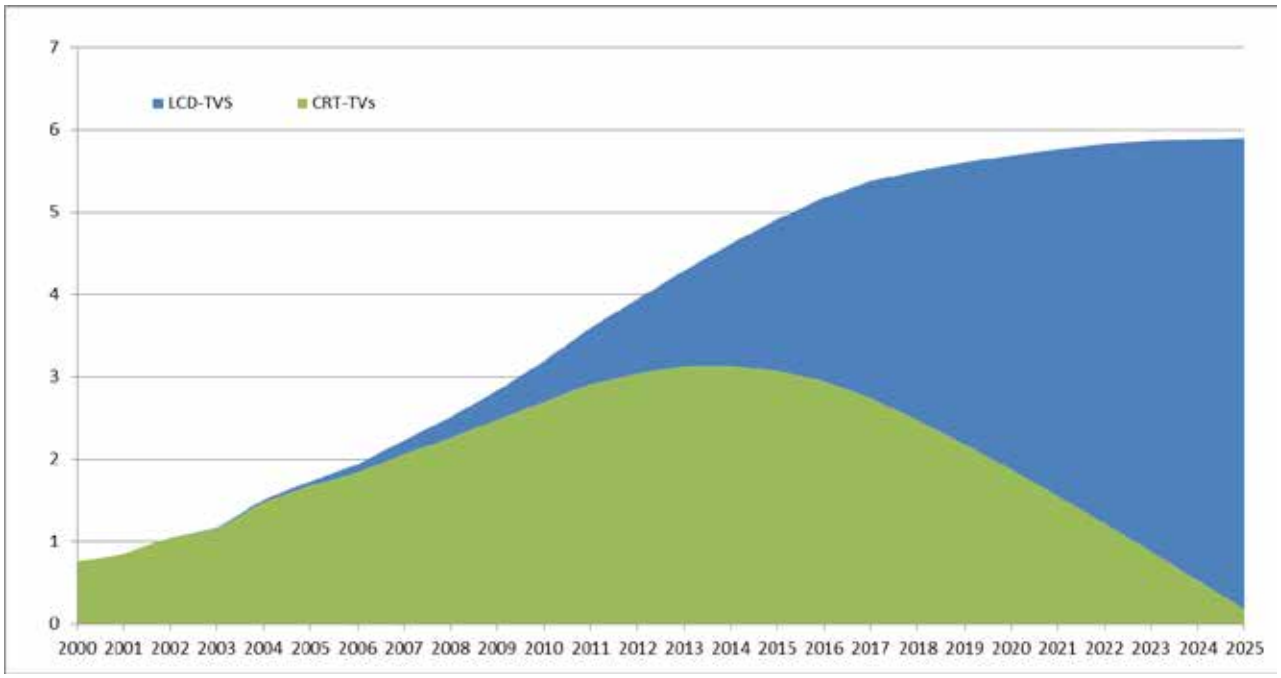
Thus, the modelling exercise assumes that this trend will continue for some years before reaching more saturated levels of above 70-80 % between 2013 and 2016. Here, it has to be considered

that until today, a significant share of households are not connected to the electricity grid (see section 1.2), thus being unable to make use of TVs. This fact also causes doubts regarding a TV-penetration rate of 89% in 2009 published by Amoyaw-Osei et al. (2011). While this figure might be plausible in some urban regions, it seems less plausible for peripheral regions such as rural settlements in the northern parts of the country[17].

Generally, it is assumed that the total number of installed TVs constantly surpasses the number of households with TV by 10%. These additional 10% are mainly TVs installed in bars, restaurants, hotels and offices as well as in households owning more than one TV.

For the split between CRT TVs and flat-screen TVs it is assumed that the transition to flat screen will take considerable longer than in the computer monitor segment. This delay is caused by longer life spans of TVs, which also lead to a prolonged influx of second-hand TVs from industrialized countries.

Figure 25 Projection of the number TVs (CRT and LCD TVs) in use in Ghana [in millions]



Source: Projections by Oeko-Institut.

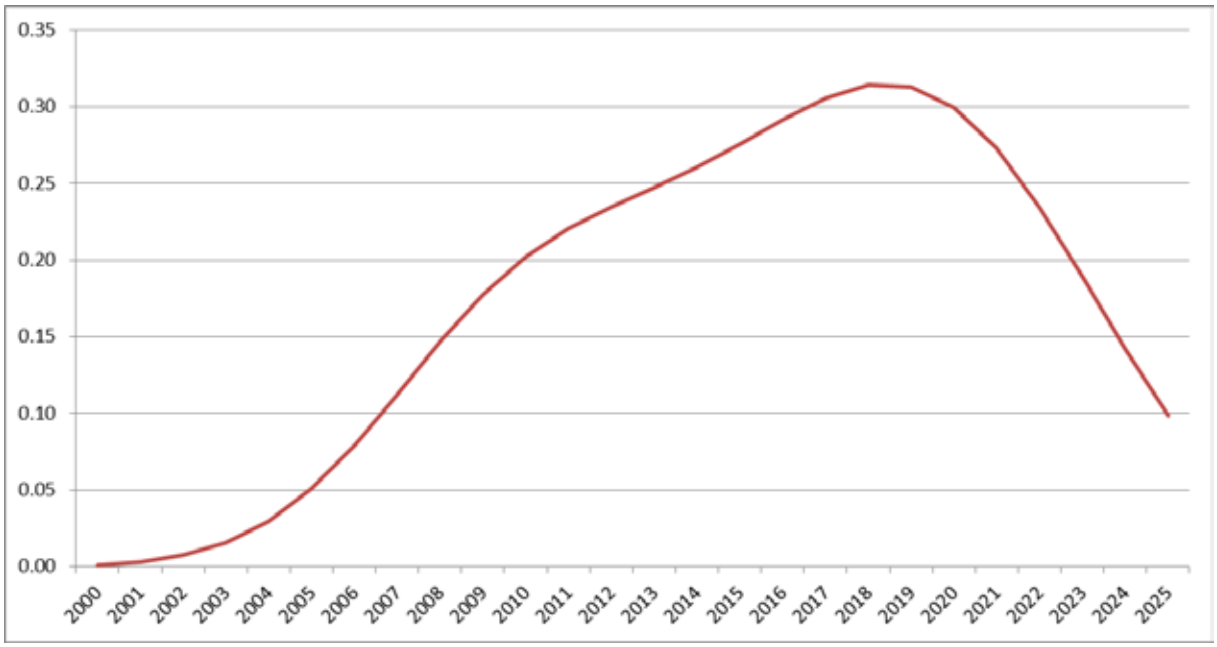
As Figure 25 shows, in the projections the use of CRT TVs peaks in 2014 at value above 3 million devices to constantly decrease afterwards to a residual of around 180.000 devices in 2025. At the same time, it is estimated that the first LCD TVs entered the Ghanaian market around 2003. From 2017, it is projected that the share of LCD TVs is higher than for CRT TVs. In 2025 it is projected that 5.72 million LCD TVs are in use in Ghana.

[17] This high value might result from the methodological approach taken by Amoyaw-Osei et al. (2011), which included a household survey carried out in the Accra-Tema region (n = 64 households). Although various correction-factors were considered by the study team, an extrapolation of such a geographically limited survey to all households in Ghana almost inevitably leads to uncertainties.

2.4.1. CRT TVs

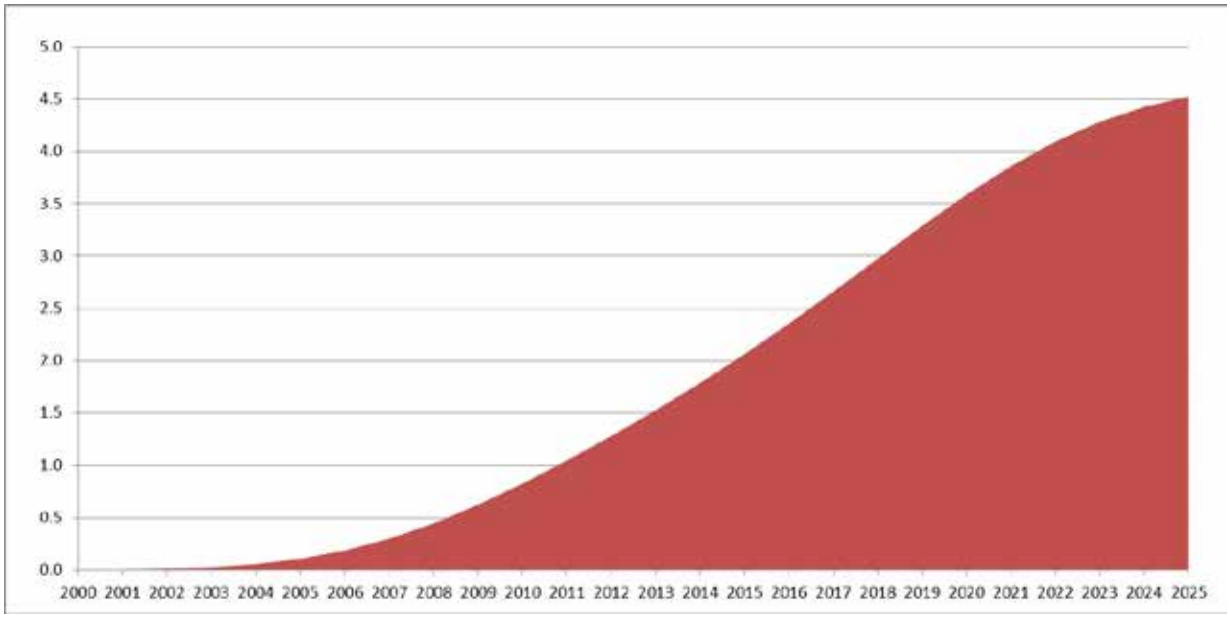
Furthermore, an average life time of 10 years (mean) and a standard deviation of 3 years around a Gaussian normal distribution are used for the calculations. In the case of CRT TVs, this leads to an annual number of end-of-life devices as illustrated in Figure 26. Accordingly, the number of EoL CRT TVs per year increases steeply until 2009/10; the growth is muted as EoL LCD TVs become relevant. The annual number peaks around 2018 at 310,000 EoL devices. The annual projections translate into cumulative projections as illustrated in Figure 27. The cumulative number of EoL-CRT TVs sum up to around 4.5 in 2025 provided that CRT TVs are not dismantled or recycled.

Figure 26 Projection of the number of EoL CRT TVs per year in Ghana from 2000 to 2025 [in millions]



Source: Projections by Oeko-Institut.

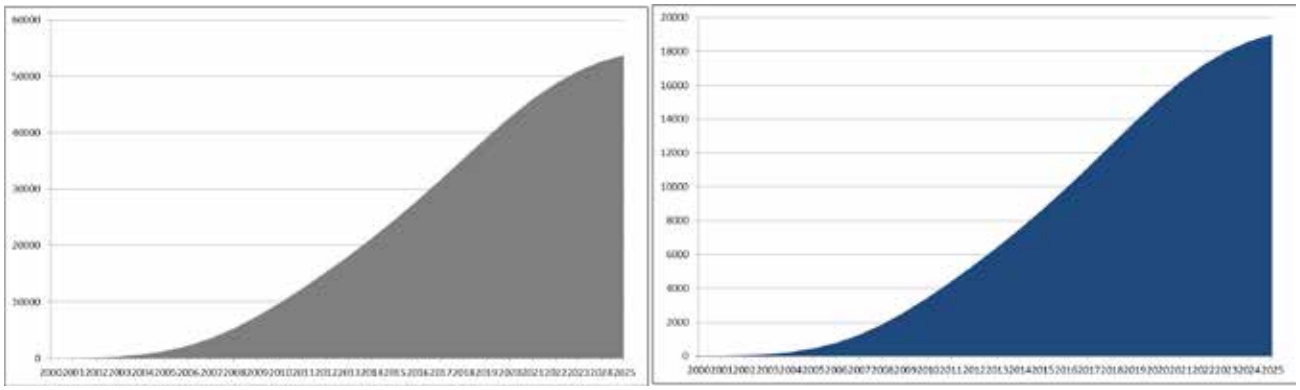
Figure 27 **Projection of the cumulative number of EoL CRT TVs in Ghana from 2000 to 2025 [in millions]**



Source: Projections by Oeko-Institut.

It is further assumed that one CRT TV has a weight of 24.14 kg (Wecycling 2011, Bleher 2013). According to Lee 2002, the corresponding mass of plastics in one CRT TV is 4.2 kg. Moreover, Lee 2002 states that the mass portion of CRT glass of one CRT TV is 49.2 %. This implies a weight of CRT glass of one CRT TV of 11.88 kg. Both mass portions are used in the cumulative projections of CRT glass and plastics in CRT TVs until 2025 illustrated in Figure 28.

Figure 28 **Projection of cumulative potential of CRT glass and plastics in EoL CRT TVs in Ghana from 2000 to 2025 [tonnes]**



Source: Projections by Oeko-Institut.

Figure 28 shows that the cumulated weight of CRT glass of EoL CRT TVs in Ghana reach around 53.747 t in 2025; in parallel the cumulative weight of plastics in EoL CRT TVs sum up to around 19.000 t.

Table 11 provides the summary for the estimations and projections regarding CRT TVs in Ghana for the years 2010, 2012, 2015, 2020 and 2025. Beside CRT TVs in use, EoL CRT TVs per year as

well as the weight of annual and cumulative EoL CRT volumes until 2025 are listed. Furthermore, the recycling volumes (potential) for plastics, CRT glass as well as the metals gold, silver and palladium are considered. In order to calculate the metal volumes contained in the CRT TVs, a mass proportion of 0.07 g of gold, 1.2 g of silver and 0.035 g of palladium per CRT TV has been assumed.

Table 11 Estimated and projected volumes of CRT TVs in use and at end-of-life in Ghana

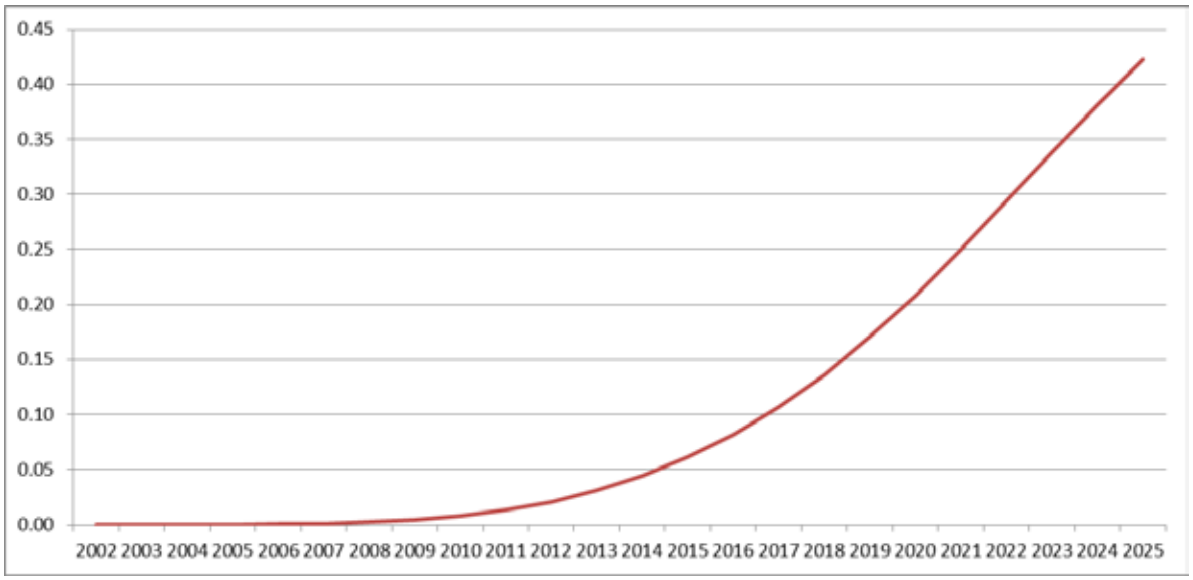
	2010	2012	2015	2020	2025
CRT TVs in use [number of devices]	2.70 million	3.04 million	3.07 million	1.88 million	0.18 million
EoL CRT TVs [number of devices] per year	0.20 million	0.23 million	0.28 million	0.30 million	0.10 million
EoL CRT TVs [weight] per year	4,885 t	5,663 t	6,658 t	7,235 t	2,375 t
EoL CRT TVs [weight] cumulative	19,921 t	30,912 t	49,827 t	86,837 t	109,241 t
Plastics in EoL CRT TVs, cumulative [weight]	3,466 t	5,379 t	8,670 t	15,075 t	19,008 t
CRT glass in EoL CRT TVs, cumulative	9,801 t	15,209 t	24,515 t	42,626 t	53,747 t
Gold in EoL CRT TVs, cumulative	0.06 t	0.09 t	0.14 t	0.25 t	0.31 t
Silber in EoL CRT TVs, cumulative	1.00 t	1.55 t	2.50 t	4.35 t	5.48 t
Palladium in EoL CRT TVs cumulative	0.03 t	0.04 t	0.07 t	0.12 t	0.16 t

2.4.2. LCD TVs

For the projections for LCD TVs, a mean lifetime of 10 years and a standard deviation of 3 years in a Gaussian normal distribution have been assumed. The according number of EoL LCD TVs is illustrated in Figure 29. As LCD TVs have been estimated to enter the Ghanian market not earlier than 2003, a relevant number of EoL LCD TVs appears only after 2010. However, the number of EoL LCD TVs is projected to see a steep increase until 2025, reaching 420,000 devices per year.

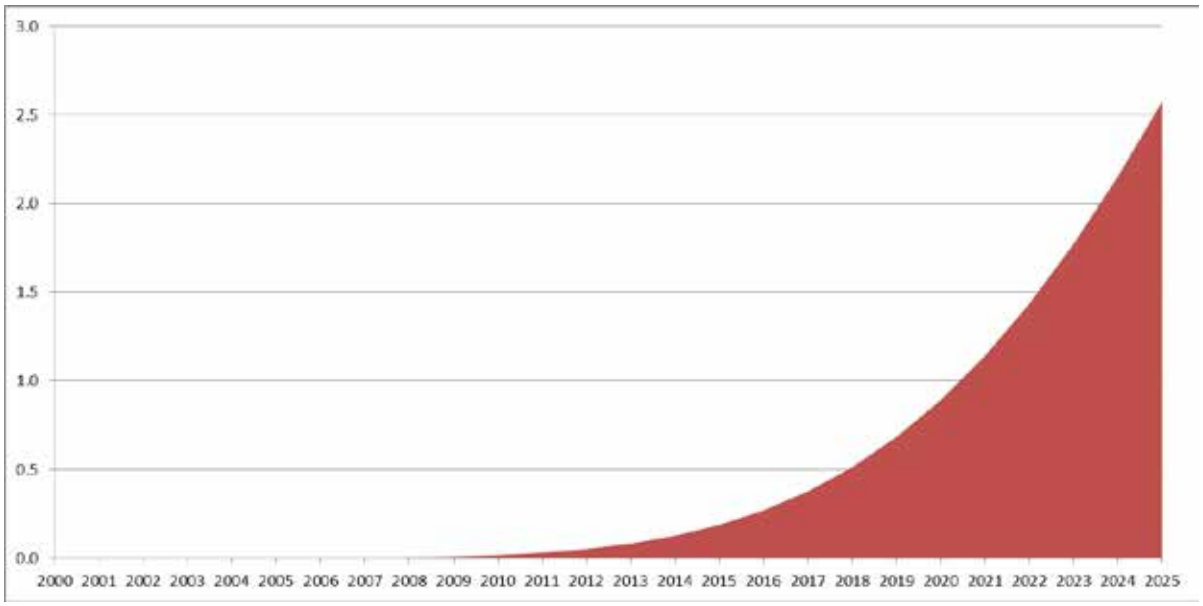
The annual projections translate into cumulative projections as given in Figure 30. The projections show that by 2025, the cumulative number of EoL LCD TVs is expected to amount to 2.6 million devices in total.

Figure 29 Projection of the number of EoL LCD TVs per year in Ghana [in millions]



Source: Projections by Oeko-Institut.

Figure 30 Projection of the cumulative number of EoL LCD TVs in Ghana [in millions]



Source: Projections by Oeko-Institut.

Table 12 provides a summary of the number of LCD TVs in use in Ghana as well as EoL LCD TVs per year. Also, it provides annual and cumulative weights of EoL LCD TVs until 2025. For this, a total weight of a LCD TV of 15 kg was assumed.

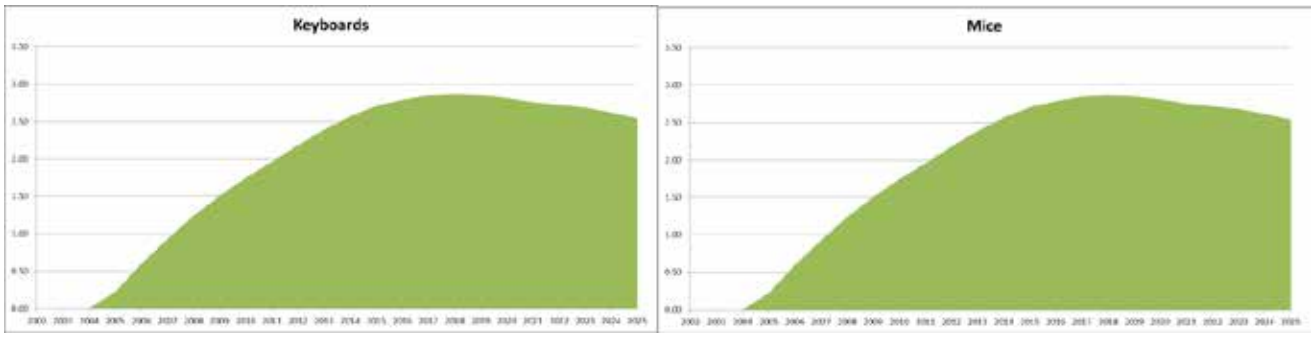
Table 12 Estimated and projected volumes of LCD TVs in use and at end-of-life in Ghana

	2010	2012	2015	2020	2025
LCD TVs in use [number of devices]	0.49 million	0.91 million	1.84 million	3.81 million	5.72 million
EoL LCD TVs [number of devices] per year	0.01 million	0.02 million	0.06 million	0.21 million	0.42 million
EoL LCD TVs [weight] per year	120.88 t	311.97 t	917.35 t	3128.92 t	6342.16 t
EoL LCD TVs [weight] cumulative	256.3 t	767.9 t	2814.0 t	13383.7 t	38659.2 t

2.5. Keyboards and computer mice

Firstly, one computer mouse and one keyboard per desktop PC have been assumed. Furthermore, it is assumed that 10% of the notebooks are equipped with an external keyboard and mouse. The projected number of keyboards and computer mice is illustrated below (Figure 31).

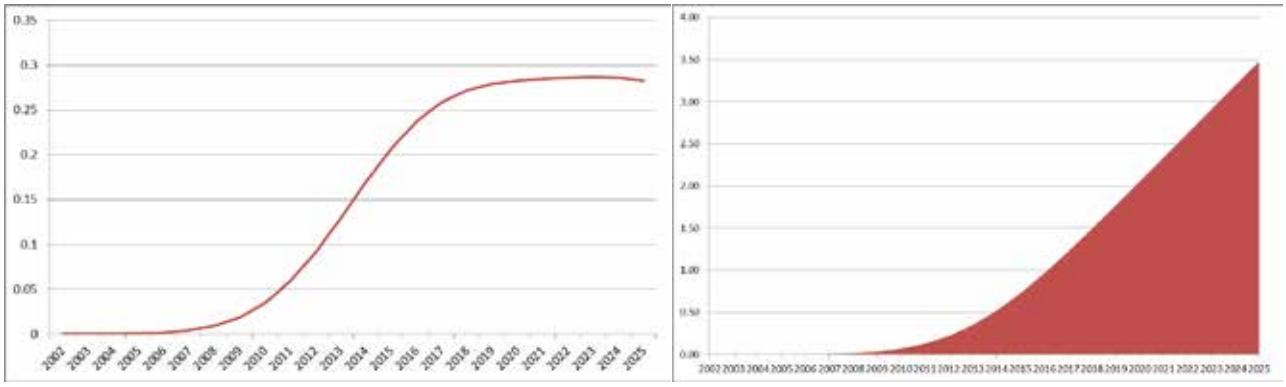
Figure 31 Projection of the number of the keyboards and computer mice in use in Ghana [in millions]



Source: Projections by Oeko-Institut.

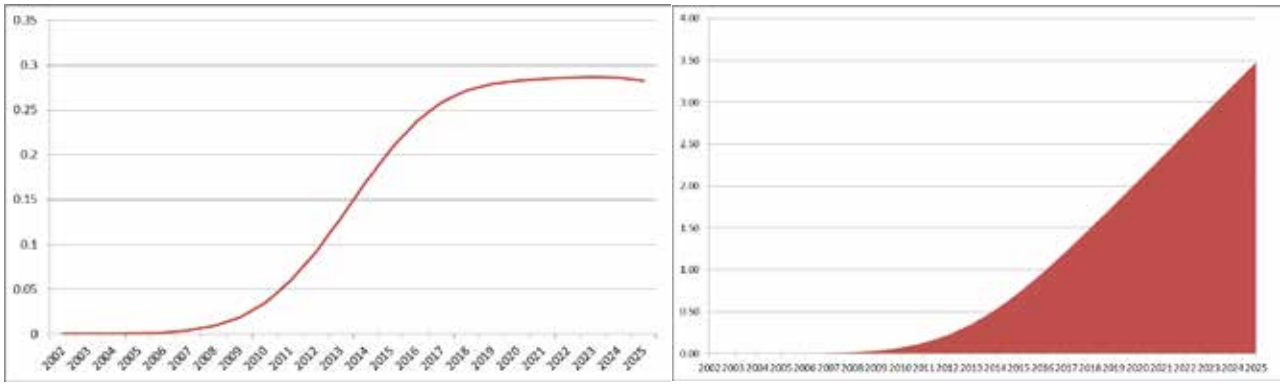
The average life time of the keyboards as well as the computer mice is expected to be ten years with a standard deviation of 3 years. Accordingly, Figure 32 and Figure 33 illustrate the number of EoL keyboards and EoL computer mice, annually and from a cumulative perspective.

Figure 32 **Projection of the annual (left) and cumulative (right) number of EoL keyboards in Ghana from 2002 to 2025 [in millions]**



Source: Projections by Oeko-Institut.

Figure 33 **Projection of the annual (left) and cumulative (right) number of EoL computer mice in Ghana from 2002 to 2025 [in millions]**



Source: Projections by Oeko-Institut.

Furthermore, the average product weight of one EoL keyboard is assumed to be 1,006 grams and of one EoL computer mouse 111 grams (EoL list Bo2W project). Table 13 provides data for the years 2010, 2012, 2015, 2020 and 2025 for EoL keyboards and EoL computer mice in terms of numbers and weights, from the annual and the cumulative perspective accordingly.

Table 13 Estimated and projected volumes of keyboards and computer mice in use and at end-of-life in Ghana

	2010	2012	2015	2020	2025
Keyboards in use [number of devices]	1.75 mio.	2.18 mio.	2.71 mio.	2.81 mio.	2.54 mio.
Computer mice in use [number of devices]	1.75 mio.	2.18 mio.	2.71 mio.	2.81 mio.	2.54 mio.
End-of-life keyboards per year [number of devices]	0.03 mio.	0.09 mio.	0.21 mio.	0.28 mio.	0.28 mio.
End-of-life computer mice per year [number of devices]	0.03 mio.	0.09 mio.	0.21 mio.	0.28 mio.	0.28 mio.
End-of-life keyboards per year [weight]	35 t	92 t	208 t	284 t	285 t
End-of-life computer mice per year [weight]	4 t	10 t	23 t	31 t	31.5 t
EoL keyboards, cumulative [weight]	68 t	219 t	728 t	2065 t	3501 t
EoL computer mice, cumulative [weight]	8 t	24 t	80 t	228 t	386 t

2.6. Passenger vehicles

The following projections of end-of-life passenger vehicles are based on the international World Bank Indicators Database (World Bank 2014). Accordingly, passenger vehicles are defined as road motor vehicles other than two-wheelers, intended for the carriage of passengers and designed to seat no more than nine people (including the driver).

The number of passenger cars in Ghana per 1000 people for the years 2005-2009 given in Table 12 (World Bank 2014). The decline in 2008/09 after the peak in 2007 can be interpreted as a consequence of the world economic crisis, following the financial crisis in 2007. Data for the years before 2005 is not available for Ghana.

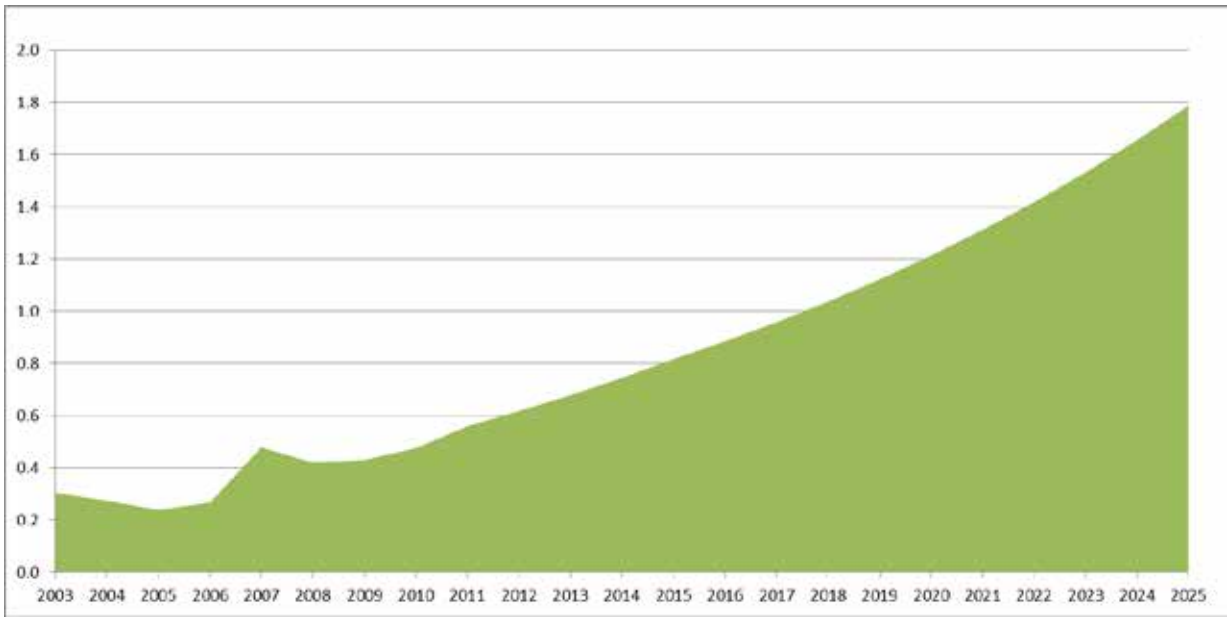
Table 14 Number of passenger vehicles per 1000 people in Ghana

	2005	2006	2007	2008	2009
Passenger vehilces per 1000 people (World Bank 2014)	11	12	21	18	18

Based on the data given above, Table 14 illustrates a projection of the number of passenger cars in Ghana until 2025.[18] The growth of passenger vehicles per 1000 people is modelled according to an expected annual GDP growth rate for Ghana.[19]. For the years 2013-15, expected growth rates of 7,4 %, 7,4 % and 7,3 % from the World Bank Database are used. For the years 2016-2025, a more conservative estimation of an annual GDP growth of 6% has been assumed. As modelled in the projections above, population growth according to UN DESA 2011 has also been also taken into account.

As a result, the total number of passenger vehicles in use is predicted to reach 1.8 million vehicles in 2025.

Figure 34 Projection of the number of passenger vehicles in use in Ghana from 2003 to 2025 [in millions]



Source: Projections by Oeko-Institut.

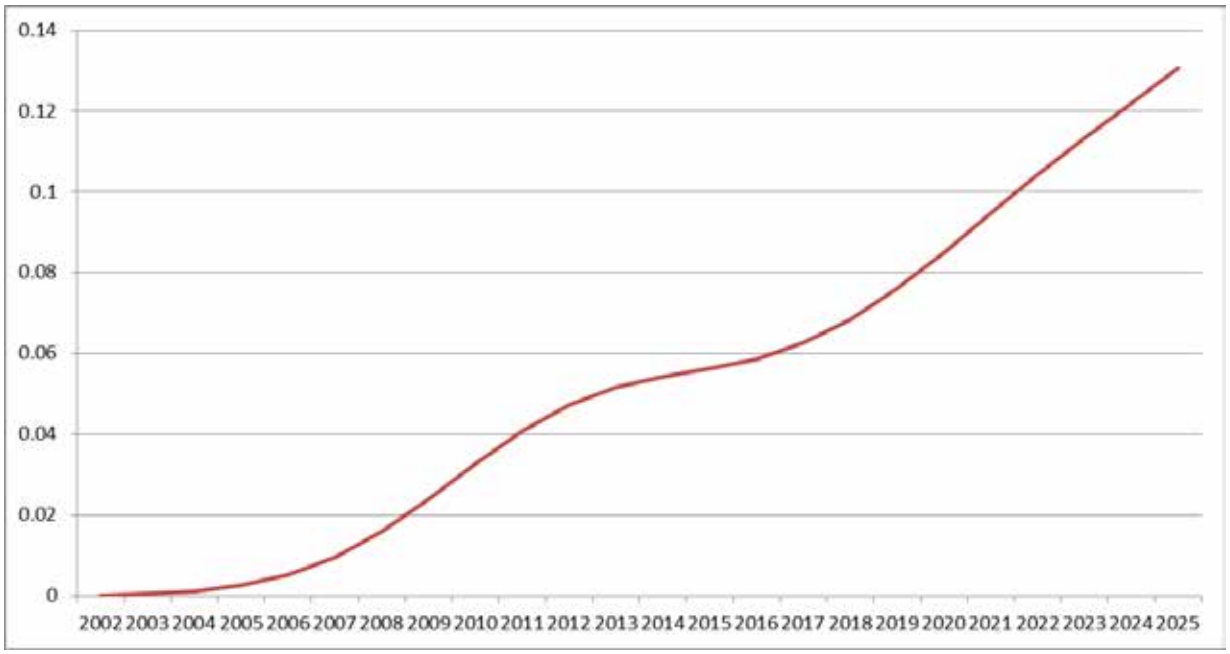
From the above illustrated data on passenger vehicles in use, the number of end-of-life (EoL) vehicles per year is derived according to the assumptions of an average life time of 10 years of a

[18] For the years 2003 and 2004 data was estimated based in data of motor vehicles in total (see section 2.7) derived by a constant share of passenger vehilces of 30%. The number of passenger vehcles per 1000 people therefore was discounted by the annual GDP growht rate.

[19] For the years 2005-2009 general GDP annual growth rate turned out to be an adequate approximate for the annual growht rate of passenger vehicles per 1000 people. This also holds as projections until 2025 are characterized by significant uncertainties.

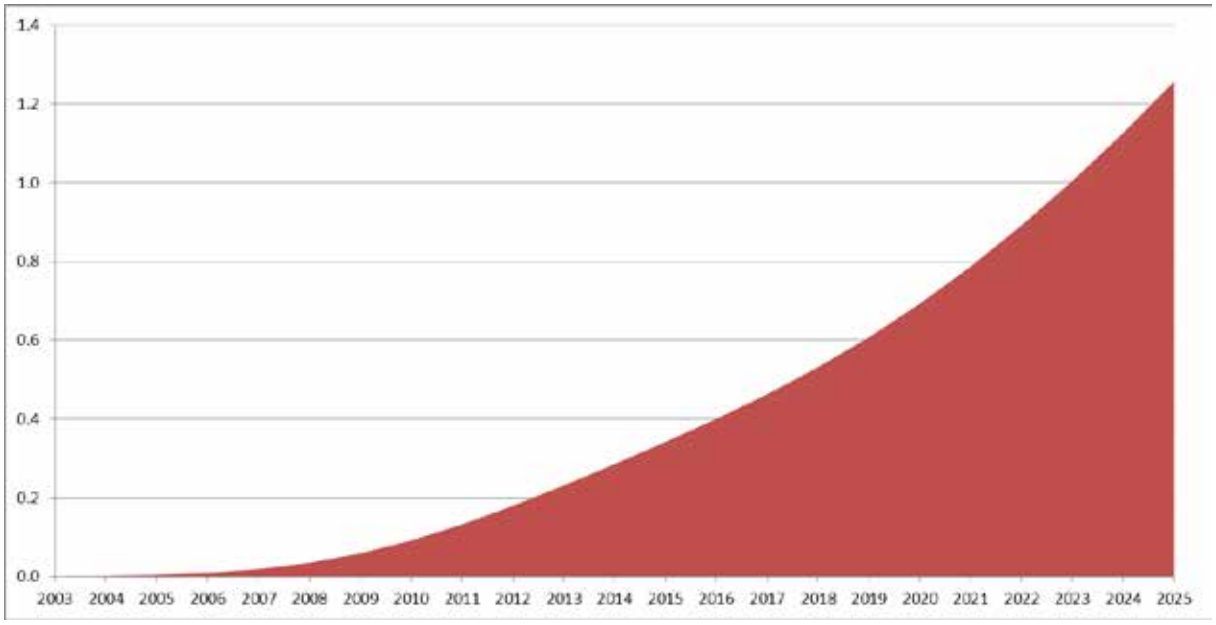
passenger vehicle. The modelling is based on a Gaussian normal distribution around this mean (μ= 10 years) and a standard deviation of 3 years (σ= 3). The average life time of 10 years is justified by the high share of used cars (at least 2nd or 3rd hand) in Ghana. Figure 35 illustrates the growth of the annual number of EoL vehicles until 2025, reaching around 130,000 cars in 2025. In parallel, the cumulative view is depicted in Figure 36, illustrating that more than 1.2 million EoL passenger vehicles are expected to have accumulated by 2025.

Figure 35 Projection of the number of EoL passenger vehicles per year in Ghana [in millions]



Source: Projections by Oeko-Institut.

Figure 36 **Projection of the cumulative number of EoL passenger vehicles in Ghana [in millions]**



Source: Projections by Oeko-Institut.

Furthermore, the cumulative projections illustrated in Figure 36 are translated into cumulative amounts (recycling potential) of gold and silver from electronics in EoL passenger vehicles.

Table 15 provides a summary of the estimations and projections of passenger vehicles in use in Ghana and the annual as well as the cumulative numbers of EoL passenger vehicles. Also, the respective cumulative volumes (recycling potential) for gold and silver from electronics in EoL passenger vehicles are listed. Data is illustrated for the years 2010, 2012, 2015, 2020 and 2025.

Table 15 **Estimated and projected volumes of passenger vehicles in use and at end-of-life in Ghana**

	2010	2012	2015	2020	2025
Passenger vehicles in use [number of vehicles]	0.47 mio.	0.62 mio.	0.82 mio.	0.09 mio.	1.79 mio.
End-of-life passenger vehicles per year [number of vehicles]	0.03 mio.	0.05 mio.	0.06 mio.	0.09 mio.	0.13 mio.
EoL passenger vehicles, cumulative [number of vehicles]	0.09 mio.	0.18 mio.	0.34 mio.	0.69 mio.	1.26 mio.

2.7. Trucks & Buses

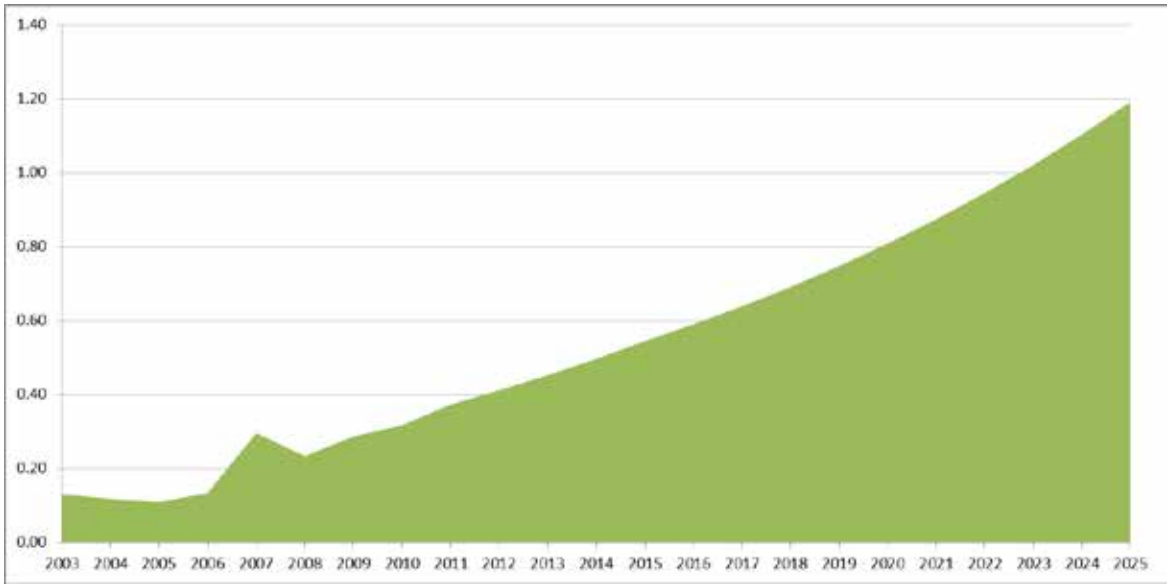
World Bank (2014) provides data on the number of motor vehicles per 1000 people in Ghana from 2003-2009 (no data for 2004). According to World Bank 2014, motor vehicles include cars, buses, and freight vehicles but do not include two-wheelers. Consequently, the number of trucks (incl. freight vehicles, buses) is derived from the motor vehicle figure by subtracting the number of passenger vehicles. The resulting number of trucks per 1000 inhabitants is provided in Table 16.

Table 16 Number of Trucks (incl. fright vehicles, buses) per 1000 people in Ghana

	2003	2004	2005	2006	2007	2008	2009
Motor vehicles per 1000 people (World Bank 2014)	21	-	16	18	34	28	30
Passenger vehicles per 1000 people (World Bank 2014)	-	-	11	12	21	18	18
Trucks (inluding buses) per 1000 people	-	-	5	6	13	10	12

In parallel to the calculation for passenger vehicles, the number of trucks in use is projected for the year 2025. As for passenger cars, the annual growth of trucks per 1000 inhabitants is based on the annual GDP growth rate. According to estimations by World Bank (2014) growth rates of 7,4 %, 7,4%, 7,3%; are assumed for 2013-2015 (for the years 2016-2025 a more conservative growth rate of 6 % is assumed). Population growth assumptions are based on UN DESA 2011 as for the other product groups.

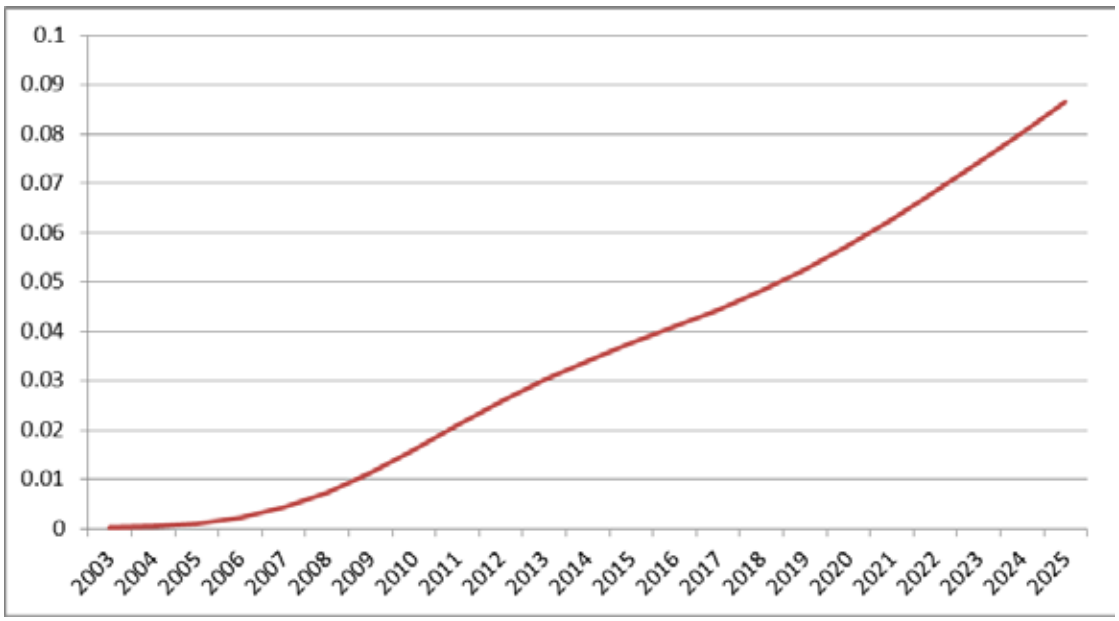
Figure 37 **Projection of the number of trucks (incl. fright vehicles, buses, etc.) in use in Ghana [in millions]**



Source: Projections by Oeko-Institut.

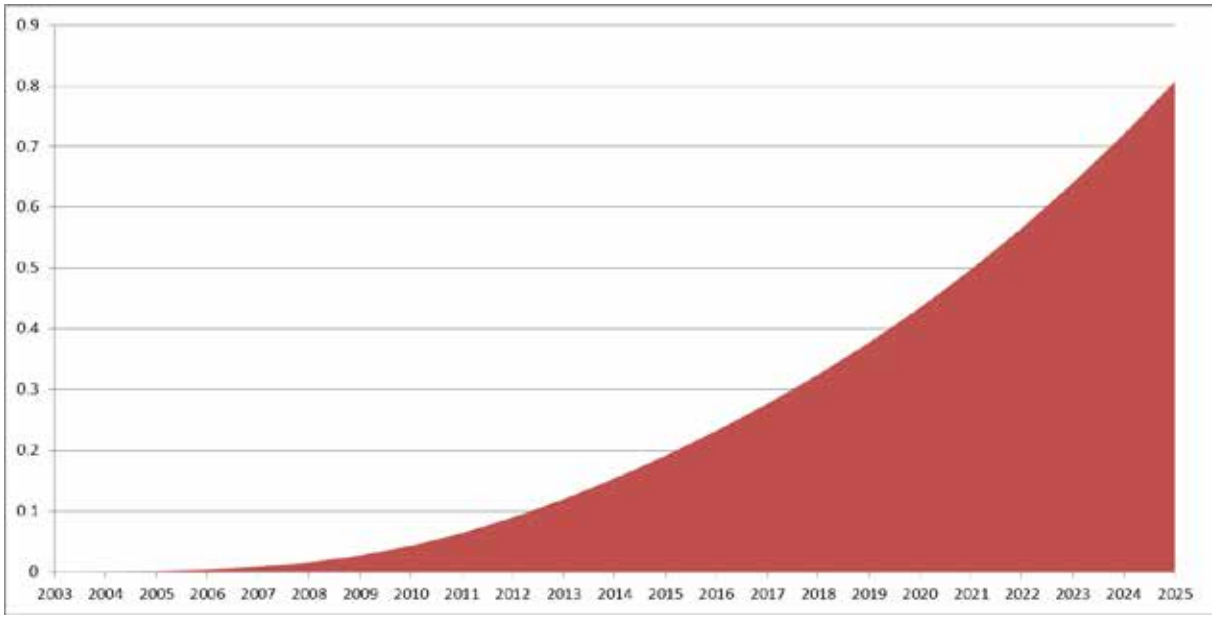
Figure 37 illustrates a predicted increase in the number of trucks in use (incl. fright vehicles, buses) to around 1.2 million vehicles by 2025. Under the assumption of an average life time of a truck of 10 years (Gaussian normal distribution, mean: μ= 10 years, standard deviation: σ= 3 years), the number of EoL trucks per year (incl. fright vehicles, buses) has been derived and illustrated in Figure 38. The cumulative view is provided in Figure 39 accordingly.

Figure 38 **Projection of the number of EoL trucks (incl. fright vehicles, buses) per year from 2003 to 2025 in Ghana [in millions]**



Source: Projections by Oeko-Institut.

Figure 39 **Projection of the cumulative number of EoL trucks (incl. fright vehicles, buses) from 2003-2025 to Ghana [in millions]**



Source: Projections by Oeko-Institut.

Table 17 provides a quantitative summary of the estimations and projections of trucks (incl. freight vehicles, buses) in use in Ghana and the derived annual as well as the cumulative EoL volumes. Data is illustrated for the years 2010, 2012, 2015, 2020 and 2025.

Table 17 **Estimated and projected volumes of trucks (including freight vehicles, buses) in use and at end-of-life in Ghana**

	2010	2012	2015	2020	2025
Trucks in use (incl. freight vehicles, buses); [number of vehicles]	0.32 mio.	0.41 mio.	0.54 mio.	0.81 mio.	1.19 mio.
End-of-life tucks (incl. freight vehicles, buses) per year [number of vehicles]	0.02 mio.	0.03 mio.	0.04 mio.	0.06 mio.	0.09 mio.
EoL trucks (incl. freight vehicles, buses) cumulative [number of vehicles]	0.04 mio.	0.09 mio.	0.19 mio.	0.44 mio.	0.81 mio.

2.8. Other devices and vehicles

The following products are relevant in terms of quantities on the market and (consequently) entering the waste stream. However, due to a lack of reliable data (comma), the products listed below are not taken into further consideration in this study:

- Motorcycles (two-wheelers)
- Forklifts (lead acid batteries)
- DVD-Players (circuit boards, magnets)
- Hi-Fi Units (circuit boards, magnets)
- Loudspeakers (magnets)
- Printers, fax, copy machines (circuit boards)
- Radio Sets (circuit board, loudspeaker)
- Video recorders (circuit boards)
- Drilling machines (NiMH batteries)
- Pocket calculators (circuit boards)
- Servers, communication devices in industry and business
- Uninterruptible Power Supplies (UPS) (lead acid batteries)

3. Work Package 3.1: Status analysis regarding collection, sorting and pre-treatment in Ghana

3.1. Waste electrical and electronic equipment

City Waste Recycling Ltd. is currently the only formal e-waste recycling enterprise in Ghana. The company uses a facility located on the outskirts of Accra to dismantle various types of electrical and electronic equipment, including TVs, information and communication technology (ICT) and refrigerators. TVs, ICT-devices and most other equipment is manually dismantled and sorted into its main fractions (steel, aluminium, copper, printed wiring boards, cables, plastics, CRT-glass). Input of e-waste is mostly secured via business-to business arrangements. Therefore, City Waste Recycling Ltd. primarily addresses e-waste generated in offices and businesses operating in the Greater Accra Region. Nevertheless, the company plans to establish a country-wide collection system with collection points in all major urban areas. It is planned that these collection points offer fixed amounts of cash money for each (complete) device handed over. With this strategy it is hoped to establish a link between the informal collectors and City Waste Recycling Ltd. so that also e-waste from small businesses and private households will enter the system.

In early 2013, City Waste Recycling started the recycling of fridges, which are collected during a new-for-old rebate programme initiated by Ghana Energy Commission and supported by UNDP-GEF. The programme plans to deliver 50,000 new fridges to Ghanaian households in exchange for functioning old devices within three years. The old devices are delivered to City Waste Recycling, where the cooling gas and oil from the cooling circuit is extracted. The gas (a mixture of the CFC R12, R134a and R600a) is destroyed under controlled conditions. After this degassing, the fridges are manually dismantled. While metals are managed in parallel to the metals from other e-waste recycling processes, the foams, which partly contain the CFC R11 or R134a are stored awaiting future solutions. The plastic cases are broken into pieces of roughly 10 cm x 10 cm and stored until sufficient volumes are available for export to downstream markets.

While *City Waste Recycling Ltd.* marks the only formal e-waste recycling enterprise, there are some formal e-waste collection efforts:

- The Amsterdam based organisation *closing the loop*, which is linked to the company *tech returns* is organising waste mobile phone collection focusing on B2B-collection. The collection is at least partly funded by *Fairphone*, which claims to transfer US$ 3.00 for each sold smartphone for mobile phone collection and recycling projects. According to DUH (2014), *closing the loop* plans to collect at least 100,000 end-of-life mobile phones and rechargeable batteries in Ghana which will be exported to Belgium for recycling at *Umicore*.
- *Nokia* initiated a collaboration project with *City Waste Recycling Ltd.* on mobile phone collection in late 2013. It aims at collecting waste mobile phones and parts of waste mobile phones from repair shops in Accra. As repair shops primarily work for private consumers, this approach hopes to strengthen mobile phone collection beyond B2B models. The collected waste mobile phones will be managed by *City Waste Recycling Ltd.* and exported to Belgium for recycling at *Umicore*.
- As described above, the *Ghana Energy Commission* initiated a new-for-old rebate programme for fridges. This programme has funds to collect 50,000 functioning old fridges within three years. The fridges are given to *City Waste Recycling Ltd.* for degassing and recycling.

Figure 40 Fridge-degassing at City Waste Recycling Ltd.

Source: Oeko-Institut.

Apart from City Waste Recycling Ltd. and the described formal collection efforts, e-waste is exclusively managed by the informal sector. In addition, there is a quite active repair and refurbishment sector, which is also linked to e-waste management. Both sectors were studied by Öko-Institut e.V. and Green Advocacy Ghana in 2010 (Prakash et al. 2010). The results were summarised in some publications such as Prakash et al. (2010), Manhart et al. (2010) and Manhart et al. (2011b). While the sector has undergone some changes in the last years, the main findings on structure and characteristics are still valid. These include:

- Collection and dismantling is – apart from the activities of City Waste Recycling Ltd. and the described projects on mobile phones and fridges – almost exclusively in the hands of informal actors.
- In the repair and refurbishing sector, the situation is more diverse with numerous small enterprises, which are partly registered and pay taxes to local authorities. Thus, this sector is only partly operating under informal conditions. With regards to e-waste, the sector is of relevance as its activities often comprise the use of spare parts from broken devices. Thus, repair shops are important hubs for repairable and non-reparable items and commonly frequented by informal waste collectors. It is estimated that the repair segment employs between 10,000 and 15,000 persons in the Greater Accra Region.
- Collection of e-waste is carried out with hand-pulled carts. Collectors use this carts (that are mostly rented on a daily bases from scrap dealers) to move around urban areas and ask small businesses and private households for metal-containing wastes. Thus, collectors do not

exclusively focus on e-waste, but on all types of metal containing waste. Usually, collectors offer some cash money for metal-containing waste.

- Within Accra, the collected waste is mostly transported to the Agbogbloshie Scrap Market where the devices are dismantled. The retrieved metals are sorted and sold to local traders who organise the transport to local downstream markets (available for steel and lead-acid batteries only – see section 1.3) or the export to foreign markets.
- The Agbogbloshie Scrap Market occupies an area of approximately two square kilometres within the centre of Accra. It is located close to a river (Odaw River) upstream a small lake (locally called “Lagoon”) draining into the Atlantic Ocean. While the eastern (upper) part of the area is occupied by improvised buildings and small open workshops where dismantling, storage and trading takes place, the lower parts to the north and west are periodically flooded and used for open burning of cables and electric parts (such as coils of starter engines and condenser coils of air conditioners), as well as the unregulated disposal of residues such as plastics and foams.
- The majority of the workforce in collection and dismantling originated from the poor and rural northern parts of Ghana. For these migrants, the scrap metal business is one of the few sectors, were they can start earning money without prior training or investments. Many of the people working in the scrap metal business maintained their ties to the rural northern parts of Ghana and travel back to their family villages during peak seasons in farming.
- While daily revenues (for an average of 10-12 working hours) can range between US$ 2.00 and US$ 9.50, there are also many collectors and recyclers that earn much less. This is particularly the case for collectors that cannot offer cash money for metal containing scrap. It also has to be considered that income is only available during working days and that – due to the informal nature of the sector – no social insurance systems exists. Furthermore, the income is mostly used to sustain other family members so that it can be assumed that many informal collectors and recyclers life of less than US$ 1.25 per day[20].
- Because work in the scrap metal business is physically very demanding, it is mostly carried out by males above the age of about 14 years. Nevertheless, child labour was also observed – mostly (but not exclusively) for tasks not involving heavy weights (e.g. dismantling of small motors). Due to internal codes in the scrap metal sector, women are not allowed to carry out physical demanding work or to actively burn cables and other types of wastes. Nevertheless, many young women care for supply with water and snacks and are therefore also present on the burning sites.
- It is estimated that between 4,500 and 6,000 persons are active in the informal collection and recycling of e-waste in the Greater Accra Region.

[20] The threshold of US$ 1.25 per day marks the internationally agreed boundary of extreme poverty.

Figure 41 Cable burning at Agbogbloshie Scrap Market in Accra. [21]

Source: Oeko-Institut.

Furthermore, Amoyaw-Osei et al. (2011) estimated the achieved collection rates of the informal e-waste collection in Ghana. They concluded that the existing informal e-waste collection (which is mostly tied to recycling practices as those observed on Agbogbloshie Scrap Market) achieves collection rates as high as 95 %.

3.2. End-of-life vehicles

There is currently no formal recycling and end-of-life management of end-of-life vehicles (ELV) in Ghana. One investment (Waste Recycling Ghana Ltd.), which installed a hall and some shredding machinery in Tema, originally planned to enter ELV-recycling in Ghana but is currently not operational.

[21] The photo was taken in 2010 at a time when car tyres were still used to light cable fires. Today, car tyres are only used when hot fires are required (e.g. to melt aluminium).

Figure 42 The non-operational ELV recycling enterprise Waste Recycling Ghana Ltd.

Source: Oeko-Institut.

Around 2009 and 2010, the company offered cash-money (around US$ 100) for waste passenger cars in newspaper advertisement. Despite the offer to pick-up the sold cars, this campaign did not result in any ELV influx. One possible explanation is the fact that ELVs are sold part-by-part to informal collectors and scrap dealers, which might result in revenues above US$ 100 for the original owner.

In the second half of 2013, City Waste Recycling Ltd. Started to collected used lead-acid batteries (ULABs). The batteries are collected and stored with acid and packed and exported according to international standards. A first shipment of batteries (around 20 t in a 40-feet-container) was delivered to Johnson Controls' lead recycling plant in Krautscheid (Germany) in December 2013 / January 2014. This export stream currently marks the only management option for used lead-acid batteries in Ghana that is in line with established environmental standards.

Figure 43 Used lead-acid batteries from Ghana at Johnson Control's lead smelter in Krautscheid, Germany.

Source: Johnson Controls.

Apart from these activities, repair shops and informal recyclers are currently the most important factor in ELV recycling in Ghana. Dismantling is often carried out in car-repair clusters where many parts can directly be used for the repair of other vehicles. While there are numerous of such clusters distributed over the whole country, the most important one is located in Kumasi, which is commonly known as one of the region's most important hub for vehicle spare parts and car repair services. The cluster, which is known as the "Magazine", was visited by the project team in June 2013. Despite difficulties to get a comprehensive overview over the market and its various segments, the following observations were made:

- The cluster roughly covers an area of some few square-kilometres. Nevertheless, not all of this area is occupied by car repair and dismantling businesses, but also with other functions (e.g. access roads, housing, shops).
- For newcomers, the market seems quite unstructured. Nevertheless, insiders report that the various economic activities well complete each other and that the network ties within the cluster guarantee a smooth exchange of spare parts and services.
- The cluster comprises segments with registered companies that are housed in mid-sized concrete buildings and open working space. One of these companies was visited by the project team. The owner maintained networks with car repair shops and scrap yards in other countries (also European countries) and introduced basic measures to avoid oil spills (concrete covers for work space and saw dust as oil binding agent). This type of company is mainly located on the main access roads to and within the cluster.
- Other parts of the clusters are only accessible via small, unpaved secondary roads. These parts typically host more basic facilities with predominantly small improvised buildings and working

and storage space on bare soil. It is assumed that a large portion of these small workshops operate under informal (non-registered) conditions.

- Compared to other car repair clusters, the area is quite diverse. In particular, various industries developed that make use of the locally generated scrap. This includes blacksmiths using scrap steel heated over coal-fires, workshops using high quality steel parts to manufacture production machinery such as plastic extruders, and coal-fires shaft furnaces remelting motor blocks into gully covers and millstones for bakeries and the local gold mining industry. Some of these companies developed into important local businesses employing a significant amount of people.
- Metal recycling is an important business throughout the cluster. Besides the described activities for scrap steel and cast-iron, also cable burning was observed. In addition, spent car catalysts and waste printed wiring boards are traded commodities.

Figure 44 Steel-casting in a local steel-smelter in the car repair and recycling cluster "Magazine" in Kumasi.

Source: Oeko-Institut.

In the Accra-Tema region the Agbogbloshie scrap market (see section 2.7) also plays a role in the recycling of ELV-parts. Although end-of-life vehicles do not visibly dominate this market, the informal collectors frequently bring in parts and components from ELVs that are further dismantled within Agbogbloshie. In particular, the following processes are routinely carried out in and around the market:

- Manual dismantling of motors to retrieve aluminium;

- Open burning of cables to retrieve copper;
- Fire-heating of starter engine coils to retrieve copper.

All of these processes are known to have severe impacts on human health and the environment. While motor dismantling in Agbogbloshie is associated with emissions of waste oil, open burning of cables and fire-heating of starter engines generate and emit persistent organic pollutants (POPs). According to calculations by Amoyaw-Osei et al. (2011), the cable fires in the Greater Accra region cause dioxin emissions equalling 0.13-0.3 % of the total dioxin emissions in the EU15, Norway and Switzerland in 2005. According to the authors, 80-90 % of the cables burned in Agbogbloshie are from waste vehicles and 10-20 % from waste electrical and electronic equipment.

In addition to these processes, lead smelting from used lead acid batteries (ULABs) was observed in Agbogbloshie until 2010. According to the Scrap Dealers Association, this process was formerly carried out by only one individual. The open smelting activities stopped after this individual deceased (SDA 2012). Today, ULABs are collected and temporarily stored in Agbogloshie as well as in many other car repair and recycling clusters before being sold to the only domestic lead smelters (see section 1.3) or exported. According to PiD (2009), the batteries are routinely opened to drain the acid before transport. This practice is carried out to reduce transport weight as well as because most local buyers solely pay for drained batteries.

Other non-valuable fractions such as glass and cushion are disposed uncontrolled. Tyres are partly used to start cable-fires. Thereby, the tyres are used to generate high temperatures to reach the burning point of cable insulation[22].

The whereabouts of valuable fractions such as catalytic converters are largely unknown. Nevertheless, there is some anecdotic evidence that catalytic converters are exported by sea or air from West-African countries to non-African destinations (personal communication with one trader of scrap material).

While scrap-steel produced in and around the Agbogbloshie scrap market is mostly delivered to secondary steel-plants in Tema.

[22] This practice was routinely observed in Agbogbloshie until around 2011. Today, cable fires are mostly started using foams from waste fridges. According to informal recyclers, tyres burn so hot that they melt aluminium, which is mostly not intended by the informal recyclers. Only in some cases (e.g. heat exchange device of air conditioners) recyclers aim to liberate copper from aluminium by melting of all aluminium-parts. In these cases, tyres are still used.

4. Literature

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5. Annex

Data base for basic data in Ghana (population, households)

Calculations and projections are based on the population size and number of households.

- Data for the Ghanian population size has been based on UN DESA 2011: United Nations, Department of Economic and Social Affairs, Population Division: World Population Prospects
- The number of households has been based on ITU (2012) data.

Assumptions for mobile phones in Ghana

The following assumptions were made for the calculations and projections in this study:

- Lifetime mobile phone (without battery): 6 years (due to high share of used phones)
- Lifetime battery of a mobile phone: 3 years
- 10% adjustment of figures of mobile subscriptions due to uncertainties (90% of subscription are active mobile phones)
- Normal distribution for mobile phones without battery: μ= 6 years; σ= 2.
- Normal distribution for mobile phone batteries μ= 3 years; σ= 1.
- Data for 2002-2011 contracts was based on ITU (2012)
- 2012-2015 projections have been based on own estimations (subscription growth 2012:18% / 2015: 6% / 2016: 3 %)
- It has been assumed that by 2017, market penetration will be reached at 1.2 active mobile phones per inhabitant.
- Average weight per mobile phone without battery and without charger: 110 grams
- Average weight per mobile phone battery: 30 grams
- Gold content per average mobile phone: 0.024gram
- Silver potential in one average mobile phone: 0.24 grams
- Palladium potential in one average mobile phone: 0.012 grams
- Copper potential in one average mobile phone: 8 grams
- Plastics potential in one average mobile phone: 20 grams
- Cobalt potential in one average mobile phone battery: 3.6 grams

Assumptions for computers in use and in waste in Ghana

The following assumptions were made:

- Data based on ITU 2012 data: International Telecommunication Union: ICT Indicators 2012 database. Geneva, 2012.
- The number of households based on ITU 2012.
- The percentage of households with a computer will reach 34% in 2025 (Assumption Oeko-Institut); the other 66% are used in enterprises and public institutions.
- It is assumed that the percentage increase of households using a computer will decrease from 12% in 2013 to 2% in 2025.
- The share of notebooks of the total number of computers starts at 5% in 2005 and reaches 70% in 2025 (Assumption Oeko-Institut)
- Life time of a computer (both desktops and notebooks) is conservatively assumed to be 4 years (assumption Oeko-Institut). In Ghana around 50% of computers in use are second hand.
- Normal distribution for life times of notebooks and desktops: μ= 4 years; σ= 1.25
- Average weight of a computer is assumed to be 8 kg (desktop computers) and 2.5 kg (notebooks) in the period under review (Assumption Oeko-Institut)
- Gold potential in one average desktop: 0.241grams (source: Gmünder 2007)
- Silver potential in one average desktops: 1.398 grams (source: Gmünder 2007)
- Palladium potential in one average desktops: 0.099 grams (source: Gmünder 2007)
- Plastics potential in one average desktop: 722.781 grams (source: Gmünder 2007)
- Copper potential in one average desktop: 339.449 grams (source: Gmünder 2007)
- Gold content in one average notebook: 0.094grams (source: LANUV 2012)
- Silver potential in one average notebook: 0.416 grams (source: LANUV 2012)
- Palladium potential in one average notebook: 0.038 grams (source: LANUV 2012)
- Plastic potential in one average notebook: 705 grams

Assumptions for CRT and LCD monitors in Ghana

The following assumptions were used for the estimations / projection of CRT and LCD in use and at EOL:

- Number of monitors in use is based on number of computers:
  - Each desktop is equipped with 1 monitor
  - In 2014, 20% of notebooks are equipped with an additional monitor; a constant rise in the growth of the use of external monitor for notebooks from 10 % in 2002 stepwise (1% per year) to 33 % in 2025.
- Share of CRT monitors is assumed to be:
  - in 2002: 99% / 2005: 90% / 2012: 31% / 2025: 0% (from 2016 no more CRTs are put on the market, phase out of CRT´s in 2020);
- Life time of CRT and LCD monitors is assumed to be 4 years, due to high rates of second hand monitor imports
- Normal distribution for monitor life times: μ= 4 years; σ= 1.25
- The average weight per CRT monitor is 14.230 kg (source: Wecycling 2009) and for one LCD monitor 4.7 kg (source: empa 2011)

Assumptions for CRT and LCD TVs in Ghana

The following assumptions were used for the estimations / projections of CRT and LCD TVs in use and at EOL:

- Number of TVs in use is based on ITU 2012 (data available 2002-2009)
- IT 2012 data shows that in 2002, 24 % of households were equipped with a TV; by 2009, 47.4 % of households were equipped with a TV.
- It is assumed by Oeko-Institut that market saturation is reached by 2025 when 94,5% of households in Ghana are expected to be equipped with a TV.
- An additional 10% is assumed for all TV figure in order to account for TVs in bars, restaurants, hotels, offices, second TV in households. This is estimated for the whole period (assumption by Oeko-Institut)
- The share of CRT TVs is assumed to be 77% by 2012 and 33% by 2020 by Oeko-Institut. It is assumed that the last CRT TV was put on the market in 2020.
- Lifetime of a CRT TV is assumed to be 10 years due to the high rate of used TVs in Ghana
- Normal distribution for CRT TV life times: μ= 10 years; σ= 3
- Lifetime for a LCD TV is assumed to be 10 years
- Normal distribution for LCD TV: μ= 10 years; σ= 3
- The average weight of an end-of-life CRT TV is assumed at 24.140 kg (source: Wecycling 2009) and at 15 kg for an end-of-life LCD TV (source: Manhart et al. 2011).

Assumptions for keyboards and computer mice in Ghana

The following assumptions were used for the estimations / projections of keyboards and computer mice in use and at EOL:

- Life times of keyboards and computer mice are assumed to be 10 years, respectively (assumption by Oeko-Institut).
- Normal distribution for keyboard and computer mice life times: μ= 10 years; σ= 3
- It is assumed that each desktop is equipped with a keyboard and computer mouse (assumption by Oeko-Institut).
- It is assumed that by 2013, around 10% of notebooks will be equipped with a keyboard and a computer mouse (assumption by Oeko-Institut)
- The average weight of a keyboard is assumed to be 1 0006 grams (Eol list Bo2W project)
- The average weight of a computer mouse is assumed to be 111 grams (EoL list Bo2W project)

Assumptions for passenger vehicles in Ghana

The following assumptions were used for the estimations / projections of passenger vehicles in use and at EOL:

- The life time of a passenger vehicle is assumed to be 10 years (assumption by Oeko-Institut)
- Normal distribution for the life time of a passenger vehicle: μ= 10 years; σ= 3
- The number of passenger vehicles has been based on the World Bank Indicators Database http://data.worldbank.org/indicator
- Passenger cars refer to road motor vehicles, other than two-wheelers, intended for the carriage of passengers and designed to seat no more than nine people (including the driver).
- For the projection of the growth rate of passenger vehicles per 1000 inhabitants, the estimated annual GDP growth rate of 7.4% for 2013 and 2014, and 7.3 % for 2015 were used as an approximation (World Bank 2014); A more conservative assumption was made for 2016-2025 (6 % annual GDP growth).

Assumptions for trucks in Ghana

The following assumptions were used for the estimations / projection of trucks in use and at EOL:

- According to World Bank (2014), motor vehicles include cars, buses, and freight vehicles but do not include two-wheelers. Population refers to the midyear population in the years for which data are available.
- Trucks are defined as all motor vehicles excluding two-wheelers and passenger vehicles They include freight vehicles as well as buses.
- The life time of a truck / bus is assumed to be 10 years due to the high share of used vehicles in Ghana (assumption by Oeko-Institut)
- Normal distribution for the life time of trucks: μ= 10 years; σ= 3
- The number of passenger vehicles has been based on World Bank Indicators Database http://data.worldbank.org/indicator
- For the projection of the percentage increase of trucks / buses per 1000 inhabitants, the estimated annual GDP growth rate of 7.4% for 2013 and 2014, and 7.3 % for 2015 are used as an approximation (World Bank 2014); A more conservative assumption of 6% annual GDP growth is assumed for 2016-2025.