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Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana

commissioned by

**the Inspectorate of the Ministry of Housing,
Spatial Planning and the Environment of the
Netherlands (VROM-Inspectorate) and the
Dutch Association for the Disposal of Metal
and Electrical Products (NVMP)**

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List of acronyms and abbreviations

ABS	Acrylonitrile Butadiene Styrene
AMA	Accra Metropolitan Assembly
BCCC	Basel Convention Co-ordinating Centre
CAR	Climate Action Reserve
CDM	Clean Development Mechanism
CFC	Chlorofluorocarbon
CIA	Central Intelligence Agency
CPI	Corruption Perception Index
CRT	Cathode Ray Tube
EAA	European Aluminium Association
EEE	Electrical and Electronic Equipments
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
GDHS	Ghana Demographic and Health Survey
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHS	New Ghanaian Cedis
GNI	Gross National Income
GRI	Global Reporting Initiative
GSS	The Ghana Statistical Service
HDI	Human development Index
HFC	Hydrofluorocarbon
ICSG	The International Copper Study Group
ICT	Information and Communication Technologies
ILO	International Labour Organization
IRS	Internal Revenue Service
ISO	International Organization for Standardization
KLERP	Korle Lagoon Ecological Restoration Project
LMIS	The Labour Market Information System
NARWOA	National Refrigerator and Air-Conditioning Workshop Owners Association
NHI	National Health Insurance

NMHSPE	The Netherlands Ministry of Housing, Spatial Planning and the Environment
NVMP	E-waste Compliance Scheme
ODS	Ozone Depleting Substances
OEA	The Organization of European Aluminium Refiners and Remelters
OECD	Organisation for Economic Co-operation and Development
OLPC	One Laptop Per Child
PBB	Polybrominated Biphenyls
PBDE	Polybrominated Diphenyl Ethers
PCB	Polychlorinated Biphenyls
PCCD/ F	Polychlorinated Dibenzo-p-Dioxins and Furans
PPP	Purchasing Power Parity
PUR	Polyurethane
PVC	Polyvinyl Chloride
PWB	Printed Wiring Board
PROSA	Product Sustainability Assessment
RoHS	Restriction of Hazardous Substances Directive
SA8000	Standard for Social Accountability
SBC	Secretariat of the Basel Convention
S-LCA	Social Life Cycle Assessment
SMEs	Small and Medium Enterprises
SSNIT	Social Security and National Insurance Trust
TEQ	Toxic Equivalent
TFR	Total Fertility Rate
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
VAT	Value Added Tax
VCS	Voluntary Carbon Standard
VROM	Ministry of Housing, Spatial Planning and the Environment of the Netherlands
WEEE	Waste Electrical and Electronic Equipments
WSIS	World Summit on the Information Society

Executive Summary

Debate on environmental, health and social problems associated with the uncontrolled dumping and inappropriate recycling of e-waste has already reached the mainstream of policy-makers in developed as well as developing countries. However, most of the developing countries have not yet been able to enforce national policies and legislations for managing e-waste. Furthermore, lack of technology and skills, and unexplored business and financing opportunities, coupled with an exponential growth in the use of electric and electronic equipments in the developing countries, have led to severe challenges in terms of managing e-waste in a proper manner. As e-waste entails several toxic and hazardous substances, its improper processing, recycling and disposal leads to severe health hazards, environmental pollution and social problems, not only for the people involved directly in e-waste related activities, but also for the local communities and the society as a whole. At the same time, e-waste is also a source of different types of metals, such as gold, silver, palladium, aluminium and copper, which makes it quite an attractive source of livelihood not only for a large number of poor people in the developing countries, but also for the national and global economy where the demand for metal resources is constantly growing. So far, there is sufficient evidence to prove that in the absence of proper recycling infrastructure, collectively with the use of crude and inefficient recycling techniques in the developing countries, metals present in the e-waste are partly lost from the closed loop recycling management.

In this context, the initiation of the E-waste Africa Project under the umbrella of the Secretariat of the Basel Convention (SBC) of the UNEP, and co-managed by the national governments and authorities in African countries, has been an important step forward. The project aims at enhancing environmental governance of e-waste and at creating favourable social and economic conditions for partnerships and small businesses in the recycling sector in Africa. In particular the project seeks to better understand and regulate the transboundary movements of used and obsolete e-equipment from Europe to Africa, and also to improve the local e-waste management capacities in many African countries, such as Nigeria, Ghana, Côte d'Ivoire and Benin. Apart from dealing with a better management and control of the legal and illegal trade of used and obsolete equipment from developed to developing countries, the project has a special focus on identifying solutions for sustainable management of domestically generated e-waste too. The idea is to explore appropriate mechanisms, if any, to link the informal e-waste recycling sector in the African countries with modern high-tech metal refining enterprises worldwide with the objectives to

- treat the hazardous fractions of the e-waste in an environmentally sound manner,
- generate decent employment, income opportunities and other positive social impacts for the informal sector in African countries, and
- recover valuable materials in the e-waste efficiently.

In the SBC E-waste Africa project, Nigeria was chosen to conduct an in-depth socio-economic study of the informal e-waste sector in order to understand its strengths and weaknesses in the e-waste management. Based on this assessment, the aim was to study the feasibility of establishing international recycling cooperation between Nigeria and Europe for sustainable e-waste management.

At the same time, in 2009, environmental enforcement authorities in the Netherlands (VROM-Inspectorate) and Ghana (Ghana Environment Protection Agency, Ghana Customs Excise and Preventive Service, and Ghana Ports and Harbour Authority) signed a bilateral collaboration agreement, the so called Joint Working Programme, to:

- improve the control of transboundary movements of waste,
- prevent the unwanted import of electric and electronic waste and second hand equipment into Ghana, and
- research the possibilities for setting up a sustainable e-waste recycling management system and contribute to the decrease of negative environmental impacts of e-waste in Ghana.

As the VROM-Inspectorate and the Ghanaian authorities are already involved in the implementation of the SBC E-Waste Africa Project, the VROM-Inspectorate, along with the Dutch Association for the Disposal of Metal and Electrical Products (NVMP), commissioned the Öko-Institut e.V. to conduct an analogue to the Nigerian socio-economic and feasibility study in Ghana. Thus, this report is written within the framework of the project commissioned by the VROM-Inspectorate and NVMP. The aim was to:

- conduct an in-depth socio-economic assessment of the informal e-waste sector in Ghana, and
- assess the feasibility of incorporating the informal e-waste sector in an international recycling cooperation for sustainable e-waste management in Ghana.

The results of the socio-economic assessment, which took place primarily at the Agbogbloshie metal scrap yard in the city of Accra and for the refurbishing sector distributed over the Greater Accra region, show that between 10,000 and 13,000 metric tons of e-waste are treated annually in Ghana by the informal sector. Especially, the informal collection activities, involving door-to-door collection as well as collection from the ware houses and dump sites seem to be operating in a very effective manner. The informal collectors, also known as scavengers, buy the obsolete e-equipments from the end consumers at relatively low prices, as for instance an obsolete desktop PC for US\$ 1.0 to 2.5, and bring them to the scrap yard

for dismantling. In many cases, collectors themselves conduct the dismantling, while in other cases, they pass on the e-waste to specialised recyclers for the recovery of metals, such as aluminium, copper and steel. The total number of collectors and recyclers, who originate mostly from the northern part of the country, range between 4,500 and 6,000 people only in the city of Accra, in the whole country of Ghana between 6,300 and 9,600 people. Additionally, refurbishing of old and second-hand electrical and electronic equipments also represents an important economic activity. In Accra, between 10,000 and 15,000 people are employed in the refurbishing sector, in the whole country of Ghana between 14,000 and 24,000 people. Thus, in total, informal refurbishing and e-waste management sector employs between 20,300 to 33,600 people in Ghana, constituting about 0.19% to 0.32% of the country's total labour force. Considering a Total Fertility Rate (TFR) of 4.0 (on an average leading to 6 people in a household) for an urban household in Ghana, it can be said that countrywide between 37,800 and 57,600 people are dependent either partially or fully on e-waste collection and recycling activities by the informal sector. Simultaneously, between 84,000 and 144,000 people depend partially or fully on refurbishing activities. In total, in terms of dependence on informal refurbishing and e-waste recycling as a livelihood option, it was found that the sector is sustaining between 121,800 to 201,600 people in Ghana. This represents about 1.04% to 1.72% of the total urban population in Ghana, or 0.50% to 0.82% of the total Ghanaian population. Due to the informal nature of refurbishing and e-waste recycling sector, its true value is not reflected in the national GDP. Nevertheless, based on the data on total number of people employed in the refurbishing and e-waste recycling sector and their average salaries, it is estimated that the sector contributes between US\$ 105 to 268 million indirectly to the Ghanaian national economy.

However, most of the people employed in refurbishing and e-waste recycling sector in Ghana continue to live in extreme poverty. Monthly incomes of collectors were found to be between US\$ 70 and 140, of refurbishers between US\$ 190 to 250, and of recyclers between US\$ 175 to 285. Expert opinion suggested that these incomes could also go lower, in case regular supply or collection of e-waste is hindered. Hence, considering the partial or full dependency of family members – in urban areas up to 6 people – on the incomes from refurbishing and e-waste recycling activities, it can be concluded that most of the people related to refurbishing and e-waste recycling activities live below nationally and internationally defined poverty lines. This is a significant revelation, especially considering two important facts: (1) people related to refurbishing and e-waste recycling activities belong to the group of about 11% of the total urban population in Ghana that lives below poverty line, and (2) most of the workers of informal e-waste recycling sector originate from the northern part of the country where majority of the poor facing chronic food insecurity live. Thus, even though engaging in informal e-waste recycling sector does not necessarily ensure higher incomes, the workers still prefer this sector as they have access to regular income in the form of a rapid cash flow – an aspect which is largely absent in agriculture-driven households in northern Ghana.

Moreover, employment in the refurbishing and e-waste recycling sector involves exposure to rigorous and insecure working conditions and severe health hazards. Even children, sometimes as young as 5 years old, were observed to be involved in the recovery of materials from e-waste, earning less than US\$ 20 per month. Most of the people employed in the e-waste recycling sector, aged mostly 14 to 40 years, were found to work for 10 to 12 hours per day, i.e. 300 to 360 hours per month. On the other hand, people in the refurbishing sector worked between 8 to 10 hours per day or 210 to 260 hours per month. Although most of the workers do not have any fixed working time in terms of working hours per day or per week, on comparing the data on working hours of the people in the informal sector with those of the formal sector, it can be concluded that workers in the informal e-waste recycling sector produce between 108 to 168 overtime hours per month. Furthermore, with the exception of few workers engaged in some high-end refurbishing/ repair/ sales business, almost none of the workers employed in refurbishing and e-waste recycling sectors have any kind of employment or social security, albeit they rely on certain family-based arrangements in the e-waste recycling business due to their common origin from the north of Ghana. All the same, employment turnover in the business is quite high, often ranging between 3 to 7 years, due to employment insecurity, low incomes, rigorous working conditions and health hazards.

Health and environment risks emerge primarily due to improper and crude recycling techniques, as for instance,

- open incineration of cables and wires to recover copper, hence resulting in the emissions of dioxins and furans;
- open incineration of insulating foam, primarily polyurethane (PUR), from obsolete refrigerators, as co-fuels to sustain the fires used for burning cooling grills of air conditioners leading to the release of ozone depleting CFCs in the atmosphere;
- rudimentary recycling practices, such as breaking of CRT-monitors using stones, hammers, heavy metal rods and chisels, to recover copper and steel, results in the inhalation of hazardous cadmium dust and other pollutants;
- open incineration of e-waste plastics which is permeated with halogenated flame retardants, such as PBDEs, and plasticizers, such as phthalates

Such practices at the Agbogbloshie metal scrap yard have led to concentrations of copper, lead, zinc and tin in the magnitude of over one hundred times typical background levels, as confirmed by a Greenpeace study in 2008. Furthermore, concentration of lead in the soil and ash samples collected by the Greenpeace team in Agbogbloshie and Koforidua in Ghana were found to be as high as 5,510 mg/kg dry weight, thus clearly exceeding the limits set for residential and industrial areas (Bridgen et al. 2008). Furthermore, incineration of PBDE containing or PVC coated cables and wires at Agbogbloshie produces dioxins and furans (PCDD/Fs) of toxicity equivalent value (TEQ) 988 pg/g TEQ – much higher than acceptable limits in unpolluted or lightly polluted areas. Exposures to toxic and persistent organic chemical pollutants, as well as very high levels of many toxic metals, as described above,

may lead to the outbreak of numerous diseases and disorders for the workers and adjoining local communities, such as endocrine disruptive properties and anomalies in the immune system (Legler & Brouwer 2003), malfunctioning of kidneys (Hellstrom et al. 2001) and respiratory system (WHO 1992), lung cancer (DHSS 2005), underdevelopment of brain in children (Haefliger et al. 2009; Brigden et al. 2008) and damage to the nervous and blood system (Brigden et al. 2008). Especially, children, due to their hand-to-mouth behaviour, are one of the most vulnerable groups in areas where soils and dusts are contaminated with lead (Haefliger et al. 2009; Malcoe et al. 2002).

While in the first part of this study, the socio-economic assessment helped to understand the currently applied recycling practices in Ghana, the second part of this report describes alternative recycling technologies and management paths applied elsewhere. This was done to analyse the applicability of these recycling technologies in the Ghanaian context on the basis of their specific environmental and social benefits, and other practical considerations, such as investment and maintenance costs for setting up new facilities, availability of end processing units in Ghana etc. Best applicable technologies include skills, processes and combinations thereof, suited best for the Ghanaian context. They might not necessarily include technical installations, and hence should not be confused with the common term “best available technologies (BAT)”. Thus, the best applicable recycling technologies were analyzed and quantified, as far as possible, in terms of their economic, environmental and social improvement potentials. Drawing from this analysis, possible business models were sketched that could help to tap the described improvement potentials. Thereby, special emphasis was put on the role played by the informal sector, and on defining mechanisms to incorporate the informal sector in future e-waste implementation strategies in Ghana. The analysis was conducted for three key waste streams, namely desktop computers, CRT-devices and refrigerators and freezers with the objective to use the results as model for the management of other product groups with similar characteristics.

In case of *desktop computers*, the comparison of the presently applied recycling technologies and the best applicable technologies reveals that there are significant untapped economic, environmental and social improvement potentials. These potentials can be realised by manual pre-treatment in Ghana and export of the precious metals bearing fractions to one of the few pyrometallurgical refineries in Europe, Canada or Japan. In the Ghanaian context, the best applicable recycling technologies for desktop computers can be sketched as follows:

- house-to-house collection of e-waste;
- manual pre-treatment, including deep dismantling up to the level of parts of sub-components;
- mechanical shredding or granulation of cables;
- further manual pre-treatment of low grade copper fraction to reduce plastic content;
- refinery of steel and aluminium fraction in domestic plants;

- refinery of high grade precious metals fraction in pyrometallurgical refineries abroad;
- refinery of copper and low-grade copper fraction in copper or steel-copper refineries abroad;
- controlled incineration / energy recovery or land filling of remaining plastic fraction.

From environment's point of view, the above mentioned e-waste management system would not only lead to an export flow of high concentrations of heavy metals and organic pollutants from Ghana to state-of-the-art facilities abroad, but at the same time, it will lead to higher recovery rates – 87% above – of precious metals, such as gold, silver and palladium. Consequently, with these optimised recovery rates of silver, gold and palladium, a total of 5.23 kg CO_{2eq} could be saved per desktop computer if compared to primary mining of the same amount of metals.

In economic terms, higher recovery rates of precious metals from the recycling of one desktop computer, as achieved in the proposed state-of-the-art technologies, would lead to an increase in the revenue from US\$ 7.22 to US\$ 13.19. Under usual conditions these values can compensate the costs for manual pre-treatment, logistics, transport and refinery. From the type of operations needed in Ghana, it is obvious that this business is largely independent from investments into machinery parks or infrastructure, and that manual pre-processing operations can be run by medium and low-skilled workers. Therefore, the business is suitable to be implemented by the current informal e-waste recycling sector in Ghana.

In case of *CRT-devices*, the comparison of the presently applied recycling technologies with the best applicable technologies reveals that there are considerable environmental improvement potentials, especially in terms of managing the hazardous fractions like CRT-glass, the internal phosphorous coating and plastics. However, the environmentally sound management of these fractions is costly and would yield clearly less revenues than the presently applied recycling technologies. In the Ghanaian context, the best applicable recycling technologies for CRTs can be sketched as follows:

- house-to-house collection of CRTs and careful handling for not damaging the tubes;
- manual dismantling into main fractions;
- manual upgrading of printed circuit boards;
- compaction of tubes under a fume hood with attached filter system;
- refinery of steel and aluminium fraction in domestic plants;
- refinery of precious metals fraction in pyrometallurgical refineries abroad;
- refinery of copper fraction in copper refineries abroad;
- controlled incineration / energy recovery or land filling of remaining plastic fraction;
- careful use of glass culets in construction sector or disposal as hazardous waste;
- disposal of phosphorous dust as hazardous waste.

The comparison between the net material values of the presently applied recycling technologies and the best applicable recycling technologies shows that revenue from recycling of one CRT-TV could be increased from US\$ 7.67 to 9.84. However, this calculation does not include the costs for environmentally sound management of the CRT-glass and the disposal of the internal phosphorous coating. Considering the current oversupply of CRT-glass, leading to a situation where providers of the glass have to bear costs of about US\$ 160 per ton for its environmentally sound end-processing in copper smelters, the revenues from environmentally sound recycling of CRTs would be lower than the revenues from the currently practiced recycling (declining from US\$ 7.67 to 7.11) – not even taking into account the costs for sound disposal of the phosphorous dust and possible additional costs for the controlled incineration of plastics. Therefore, it is expected that profit-orientated enterprises will not engage in environmentally sound CRT-recycling without additional financing systems and/or other safeguard mechanisms that ensure a proper handling of all fractions of CRT-products. Thus, any business model to implement environmentally sound CRT-recycling can only be successful, if laws and regulations clearly outline the recyclers' full responsibility for all waste fractions. Additionally, sound CRT-recycling could be supported by identifying suitable management options for critical fractions. This could include:

- identification and development of disposal sites for hazardous wastes;
- minimum quotas for co-incineration of hazardous wastes in cement kilns;
- further exploring the feasibility of using CRT-glass in the construction sector.

In case of *refrigerators and freezers*, the comparison of the presently applied recycling technologies and the best applicable technologies reveals that there are significant untapped environmental and possibly economic improvement potentials. These potentials can be realised by the recovery of CFCs and HFCs from cooling circuits and foams and subsequent destruction of these Ozone Depleting Substances (ODS) in dedicated facilities. Additionally, the sound management of hazardous components and a better utilisation of the plastic fraction add to the benefits of sound refrigerator recycling. Economic benefits can be tapped, if the CFC and HFC-recovery and destruction are marketed using one of the existing emission reduction certification schemes, such as the Carbon Action Reserve (CAR) or the Voluntary Carbon Standard (VCS). In the Ghanaian context, the best applicable recycling technologies for refrigerators and freezers can be sketched as follows:

- house-to-house collection of refrigerators and freezers and careful transport to prevent leakages of the cooling circuit;
- semi-automated extraction of CFCs from cooling circuits;
- automated recovery of CFCs from foams;
- refinery of steel and aluminium fractions in domestic plants;
- export of copper fraction;
- local recycling of polystyrene;

- marketing of PUR-powder as oil binding agent;
- export and destruction of CFCs in certified facilities;
- controlled incineration / energy recovery of oil and remaining plastic fraction;
- controlled management of hazardous fraction.

From an environmental perspective, the best applicable technologies, which would recover a minimum of 90% of total CFCs contained in cooling circuits as well as foams, would lead to a proper management of up to 2–7 t CO_{2eq} per device. Together with better utilization of plastics, mainly polystyrene – a potential which is neglected in presently applied recycling technologies, revenues from CO₂ emission trading would yield much higher economic benefits. However, investment costs for setting up such facilities would range from 280,000 US\$ for basic machinery to recover CFCs from cooling circuits to US\$ 6.3 million for comprehensive recovery facilities. On the other hand, management aspects related to export of CFCs, certification and compliance within the framework of emission trading schemes, would be quite complex. Thus, informal e-waste sector might not be in the position to manage such a recycling management system on its own. However, the informal e-waste sector should still be engaged in the collection of obsolete refrigerators, their transport to the recycling facilities and the manual recycling steps. In this way, businesses would closely interlink with the current e-waste recycling structures and avoid competition in acquiring obsolete refrigerators.

It is important to perceive the recycling management options described above against possible risks and unintended side-effects. Any future implementation strategy regarding sustainable e-waste management should be careful of:

- dangers of negligence of non-valuable fractions, such as CRT-glass, plastics etc.;
- problems related to changing composition of e-waste, as for instance, increasing use of LCD screens;
- variations in resource prices;
- dangers of indirect stimulation of illegal e-waste imports.

Especially the latter point is of crucial importance, as measures to increase revenues from e-waste recycling might also indirectly stimulate e-waste imports. This is not only a problem because these imports contravene the Basel Convention, but also due to the fact that even improved e-waste recycling will continue to have negative environmental impacts in Ghana. Although such impacts can hardly be avoided for domestically produced e-waste, imported e-waste should not be tolerated in Ghana at all.

Based on the socio-economic assessment, analysis of presently applied and best available recycling technologies and risk assessment, following recommendations can be formulated for the Ghanaian government, the Ghanaian and international recycling industry and international donors aiming to support Ghana in its efforts to solve the e-waste problem:

- Incorporate the informal sector in future e-waste strategies
- Deploy manual labour for pre-processing
- Support and maintain international recycling co-operations
- Focus on high quality recycling products
- Develop regulative framework
- Develop appropriate finance mechanisms
- Provide solutions for locally generated hazardous waste
- Regulate the import of used products

Specifically, in terms of an implementation of the proposed applicable recycling technologies, it is recommended to set-up an e-waste recycling pilot project in Ghana. This project should help to overcome some of the current obstacles for improvements and maximize social, environmental and economic benefits. It should closely work with the Ghanaian authorities, the local recycling industry and international recycling networks to achieve sustainable solutions, and to test and implement the business models, as described in this report. Crucial elements of a pilot implementation project are listed below:

- Use EPA-Ghana as umbrella organization
- Conduct pilot operations in or close to existing recycling clusters
- Give priority to directly linking Ghanaian recyclers to international recycling networks
- Improve social standards
- Ensure rapid cash flow
- Focus on all e-waste fractions

1 Introduction

While the environmental problems from inappropriate recycling of e-waste have long been important topics for waste managers and policy makers in industrialised countries, it is only a few years ago, that international attention shifted towards the increasing e-waste problem in emerging economies and developing countries. For West-Africa, attention was particularly enhanced by the film “The digital dump” on e-waste imports and uncontrolled disposal in Nigeria in 2005 (Puckett 2005). The film produced by Basel Action Network (BAN) gave first insights into the rapidly increasing trade with used and obsolete electrical and electronic products from industrialised countries to port cities like Lagos in Nigeria. In 2008, Greenpeace published a report on the e-waste recycling activities in Ghana and highlighted its adverse impacts on human and environmental health (Brigden et al. 2008). In Ghana and the surrounding countries the problems with e-waste is aggravated by an ongoing stream of used and obsolete electrical and electronic equipment from industrialized countries entering African ports. Although a certain portion of this imported equipment is refurbished, many devices and components prove unsuitable for reuse and further add to the local e-waste generation problem, leading to the accumulation of large hazardous waste volumes in port cities and major refurbishment centres. On the other hand, domestic consumption of electrical and electronic devices in Ghana and other African countries is expected to increase as well. The growing e-waste volumes together with the absence of well-organized management systems have manifold impacts on the environment, local communities and the economic system in Ghana. On the other hand, besides hazardous substances, electrical and electronic equipments also contain a whole range of valuable metals like copper, palladium, gold, silver, indium and germanium that are inevitably lost if not recovered in an early stage of waste treatment. From a global perspective, this loss of scarce metals has to be compensated by intensified mining activities, which again lead to severe sustainability impacts in mining areas worldwide.

While in the beginning, focus of policy development mainly dealt with the legal and illegal trade of used and obsolete equipment from OECD to non-OECD countries, there is now a common understanding that also domestic e-waste generation needs further considerations. As internationally agreed on the World Summit on the Information Society (WSIS) in 2005, all people and societies shall make use of information and communication technologies (ICTs) to bridge the digital divide and to stimulate development. Considering widespread poverty and largely low- income households in Ghana,¹ access to low cost second-hand equipments

¹ The data presented below has been taken from the data bank of the World Bank Group (2010):

- Gross National Income (GNI) per capita in PPP (current international \$) in 2008 – US\$ 1320
- Gross Domestic Product (GDP) per capita in PPP (current international \$) in 2008 – US\$ 1463
- Poverty headcount ratio at \$ 1.25 a day (PPP) (% of population) in 2006 – 30%
- Poverty headcount ratio at \$ 2 a day (PPP) (% of population) in 2006 – 54%
- Poverty headcount ratio at National Poverty Line (% of population) in 2006 – 29%

of ICTs gain enormous importance. For instance, in line with the objective to promote an improved educational system where ICTs are widely deployed to facilitate the delivery of educational services at all levels, the government of Ghana has initiated the One Laptop per Child (OLPC) programme in primary schools. The first consignment of 1,000 computers was delivered for distribution to schools (Daily Graphic, June 2, 2009). In addition, another initiative, Laptop for Household Project aimed at providing 150,000 affordable laptop computers and accessories to individual households, was launched (Ghanaian Times (page 19), August 3, 2009). A basic second hand desktop PC in Ghana costs between US\$ 60 to 100, while a second hand notebook between US\$ 200 to 300. Compared to the costs of new electrical and electronic equipments (EEE), the prices of second hand & used EEE indicate that they are available at affordable prices for the lower and medium income groups of Ghana. Apart from benefits to the end consumers, employment opportunities are generated for the refurbishing & repair sector (Chapter 3.4.2).

With the increasing utilisation of ICTs, consumer electronics and household equipments in all world regions, e-waste volumes are rapidly growing in virtually every country. Generally, e-waste is passed by the end-consumers and refurbishing/ repair businesses via formal or informal collection agents to formal or informal material recovery & end-disposal operations. Estimates based on the socio-economic data collected in Accra reveal that in Ghana about 10,000 to 13,000 metric tons of e-waste is treated annually.² Compared to other countries in Africa (see table 1 below), this quantity is larger than in Kenya, Senegal and Uganda, and much smaller than in South Africa:

² The socio-economic data collected at the Agbogloboshie metal scrap yard in Accra indicated that each recycler at the metal scrap yard processes about 5.2 metric tons of e-waste per year in order to recover materials. Considering that about 1,500 out of total 3,000 members of the Agbogloboshie Scrap Dealer Association focus primarily on e-waste, and relying on the expert judgment that Agbogloboshie contributes about 40% to 60% to the total e-waste processing in Ghana, it was estimated that about 10,000 to 13,000 metric tons of e-waste are treated in Ghana annually. The average weight of various devices, such as PCs, refrigerators etc., were taken from Schlupe et al. 2009.

Table 1 Quantity of E-Waste generated in metric tons/year (Source: Schluep et al. 2009)

Country	Quantity of e-waste generated ³ (metric tons/year)	Assessment date
Senegal	3,730	2007
Uganda	4,390	2007
Kenya	7,350	2007
Peru	24,420	2006
Colombia	36,100	2006
Morocco	38,200	2007
South Africa	59,650	2007
Mexico	269,300	2006
Brazil	368,300	2005
India	439,000	2007
China	2,212,000	2007

Although end-of-life treatment operations of e-waste give rise to further employment and income opportunities for a large group of people, they are also associated with severe environmental and health hazards, hence diluting the overall potentials and benefits to a large extent. Thus, the e-waste problem in emerging economies and developing countries needs a twofold approach:

- improvement of the local e-waste management capacities;
- better regulation of transboundary movements of used and obsolete EEE.

This project study addresses the first demand and aims to elaborate improvement potentials through better recycling technologies⁴. Thereby, the analysis is not restricted to reducing environmental impacts, but it also focuses on multiple socio-economic aspects and looks into feasible ways to integrate the informal e-waste recycling sector into possible business models in order to identify new market niches and generate significant employment and income opportunities for the urban poor.

In order to meet these aims, the project encompasses an in-depth socio-economic study on the functioning and the sustainability impacts of the refurbishing and e-waste recycling sector in Ghana (chapter 3). In the second part of the study, the currently practiced recycling

³ The figures do not correspond to the total e-waste generation, but only to a set of e-waste categories (tracer products), for which reliable data was available. The e-waste categories considered include: ICT (PCs, printers and mobile phones), TVs and refrigerators.

⁴ In line with the analysis of the term „technology“ performed in Schluep et al. 2009, the term „technology“ in this report refers not only to „technical installations, but also to skills, processes and combinations thereof. In this respect, a systematic manual dismantling of an electronic device or a well elaborated chain of different processes is regarded as technology“. (Schluep et al. 2009)

technologies are compared with best applicable recycling technologies⁵. Drawing from these comparisons, feasible technologies and business models that have the potential to improve the environmental, social and economic profile of the Ghanaian refurbishing and e-waste recycling sector are explored. This also includes business models that are based on international co-operations between Ghanaian recycling sector and recycling companies based outside Ghana (chapter 4). From the findings, recommendations with a view to developing new market niches for the Ghanaian e-waste recycling sector are formulated (chapter 5).

This approach is based on the consideration that the transformation from the current crude recycling technologies into a more sustainable e-waste management needs a nucleus that enables multiple gains for all actors involved in e-waste management. In particular, gains must be realised for the informal sector that controls large segments of the Ghanaian recycling activities and which will play a decisive role in implementing any future e-waste management systems. Starting with such nucleus recycling activities, the general acceptance of e-waste related policies and strategies could be enhanced. Furthermore, they could help to pave the road for a sound and coherent national e-waste strategy in Ghana.

The project is funded by the Inspectorate of the Ministry of Housing, Spatial Planning and the Environment of the Netherlands (VROM-Inspectorate) and the Dutch Association for the Disposal of Metal and Electrical Products (NVMP)⁶. It is jointly coordinated by the Environmental Protection Agency Ghana (EPA Ghana), VROM-Inspectorate, NVMP, the Agbogloboshie Scrap Dealers Association, the Basel Convention Coordinating Centre for the African Region (BCCC), Green Advocacy Ghana and Öko-Institut e.V. The field work, the desk studies and analysis was conducted by Öko-Institut e.V and Green Advocacy Ghana.

The project was carried out in close co-operation with the E-waste Africa Project managed by the Secretariat of the Basel Convention. The E-waste Africa Project contains following components:

⁵ In the context of this study, the term “best applicable technology” is used instead of the commonly used term “best available technology (BAT)”. The term “best applicable technology” means a technology, including skills and processes, which is suited best to the Ghanaian context. In terms of conventional terminology “technology”, “best applicable technology” might not be equivalent to “best available technology (BAT)”.

⁶ In 2009, environmental enforcement authorities in the Netherlands (VROM-Inspectorate) and Ghana (Ghana Environment Protection Agency, Ghana Customs Excise and Preventive Service, and Ghana Ports and Harbour Authority) signed a bilateral collaboration agreement, the so called Joint Working Programme, to improve the control of transboundary movements of waste, to prevent the unwanted import of electric and electronic waste and second hand equipment into Ghana, and to research the possibilities for setting up a sustainable e-waste recycling system and thus, contribute to the decrease of environmental harm caused by e-waste in Ghana. On the other hand, the NVMP is the implementation organisation that has been commissioned by producers and importers to set up an efficient and effective collection and recycling system for discarded electrical and electronic equipment and appliances in the Netherlands. As the VROM-Inspectorate, the NVMP and the Ghanaian authorities are already involved in the implementation of the SBC E-Waste Africa Project, which also encompasses a socio-economic study of the e-waste sector in Nigeria, these authorities have sought to use the similar methodology in Ghana in order to use the synergies between the two projects, and draw comparative analysis between Nigeria and Ghana.

- **Component 1:** A fact finding study on the flows of used and end-of-life e-products into the country, in particular from European countries is carried out. Local persons were trained by international experts to undertake the field research and data collection. Investigations at exporting ports in Europe were also carried out.
- **Component 2:** Under this component, a country assessment is carried out. This country assessment encompasses the description and assessment of e-waste management practices in the formal and the informal sector, including economic and social impacts, potential impact to human health and the environment, an assessment of needs to ensure environmentally sound management, and a detailed description of the legal and regulatory infrastructures in place. The results of the country assessments are shared with national multi-stakeholder groups composed of governmental officials, representatives from the recycling sector, and the civil society and would be used for the preparation of national e-waste management plans.
- **Component 3:** An in-depth socio-economic study on the functioning and the sustainability impacts of the e-waste sector in one country (Nigeria) is prepared. This includes a feasibility study of international co-operations between African SMEs and European recycling companies by combining their specific competitive advantages in e-waste disassembly and material recovery will be explored.
- **Component 4:** Additionally, Ghanaian institutions participate in an enforcement programme on the monitoring and control of transboundary movements of used and end-of-life e-equipment and the prevention of illegal traffic. Amongst others, a training curriculum aimed at port and customs authorities, governmental officials and accreditation authorities is developed by specialized institutions. The curriculum addresses tools for customs control, characterization and classification of used and end-of-life e-equipment, institutional coordination, regulatory framework development, and criteria for the environmentally sound management of used and end-of-life e-equipment. In the context of a collaborative effort, the project proposes measures for the prevention and control of exports from Europe to Africa of used and end-of-life e-products, and facilitates the training of enforcement officers from African countries in Europe and the development of a scheme for exchanging information on end-of-life e-equipment between exporting and importing states.

Under the E-waste Africa project, component 3 is dedicated to an in-depth socio-economic study of the e-waste sector in Lagos, Nigeria. Therefore, officially, an in-depth socio-economic study does not take place in Ghana under the umbrella of the SBC E-Waste Africa project. However, the in-depth socio-economic study of the e-waste sector in Ghana, as commissioned by the VROM-Inspectorate and the NVMP, was closely linked to the E-Waste Africa project to use the synergies and avoid overlaps between the two projects. Commonly, the socio-economic study in Ghana is also referred as component 3 for the general public,

local stakeholders and experts. By aligning this project study with the E-waste Africa project, it was ensured that research information from both projects could be used for each others work. Furthermore, proposed strategies and recommendations were harmonised and jointly discussed with the relevant stakeholder groups. Thereby, the main aim was to avoid a competition of projects and e-waste related recommendations and to make best use of the expertise available in both project teams.

2 Objectives and methodological approach

The study aims to identify improvement potentials for the Ghanaian e-waste management capacities through better recycling technologies. Thereby, the analysis is not only limited to the possibilities of reducing environmental impacts, but it also focuses on multiple socio-economic aspects. The study looks into feasible ways to integrate the informal refurbishing and e-waste recycling sector into possible business models in order to identify new market niches and generate significant employment and income opportunities for the urban poor.

The study is composed of two analytical parts: The first part covers the socio-economic assessment of the informal refurbishing and e-waste recycling sector in Ghana (chapter 3). The second part covers the analysis and feasibility of recycling technologies and business models, applicable in the Ghanaian context (chapter 4). The results of the two assessments form the basis for the subsequent recommendations (chapter 5).

2.1 Socio-economic assessment

The socio-economic assessment of the refurbishing and e-waste recycling sector builds upon the UNEP/ SETAC “Guidelines for Social Life Cycle Assessment of Products” commonly referred to as S-LCA guidelines, and Öko-Institut’s sustainability toolkit “PROSA – Product Sustainability Assessment”. The S-LCA guidelines and PROSA provide a comprehensive list of socio-economic indicators that were developed from a set of about 3,500 indicators from international standards and key documents, such as ISO 26000, the Global Reporting Initiative (GRI), the UN Global Compact, the OECD Guidelines for Multinational Enterprises, SA 8000 and the ILO conventions (Grießhammer et al. 2006). Detailed descriptions of the methodologies are given in UNEP 2009 and Grießhammer et al. 2007.

The S-LCA guideline and PROSA sustainability toolkit follow the so called “stakeholder approach”. The stakeholder approach implies that different socio-economic indicators are allocated to pre-defined stakeholder categories. For the purpose of this study, three key stakeholder categories were defined to assess the socio-economic impacts of refurbishing and e-waste recycling sector in Ghana: (1) Workers, (2) Local Communities, and (3) Society.

The following table illustrates the allocation of different socio-economic indicators to the above mentioned stakeholder categories.

Table 2 Allocation of socio-economic indicators to stakeholder categories

Stakeholder Categories	Workers	Local Communities	Society
Socio-economic Indicators	<ul style="list-style-type: none"> - Safe & healthy working conditions - Freedom of association and right to collective bargaining - Equality of opportunity and treatment and fair interaction - Forced labour - Child labour - Remuneration - Working hours - Employment security - Social security - Professional development - Job satisfaction 	<ul style="list-style-type: none"> - Safe & healthy living conditions - Human rights - Indigenous rights - Community engagement - Socioeconomic opportunities 	<ul style="list-style-type: none"> - Unjustifiable risks - Employment creation - Contribution to national economy - Contribution to national budget - Impacts on conflicts

In the second step, the socio-economic indicators were fed into the so called S-LCA Assessment Sheet in order to facilitate the data collection with the help of local research partners in Ghana. The S-LCA Assessment Sheet was used to transform the socio-economic indicators into various topics. Under each topic, each socio-economic indicator was rephrased & elaborated in the form of a question that was used by local research partners during the data collection in Ghana. Additionally, a fictional example was provided next to the questions on the S-LCA Assessment Sheet to clarify which kind of socio-economic data was needed. The complete S-LCA Assessment Sheet can be found in Annex I.

Using the S-LCA Assessment Sheet, Green Advocacy Ghana conducted the data collection between December 2009 and April 2010. Data collection involved various techniques ranging from face-to-face interviews, visual inspections, transect walk and expert interviews. As Accra represents the focal point of refurbishing and e-waste recycling in Ghana, and as the city covers all product groups and product-related processes (collection, refurbishing, recycling and disposal), it was decided to limit the primary data collection for the socio-economic assessment to the city of Accra. The following figure shows the areas of data collection in Accra:

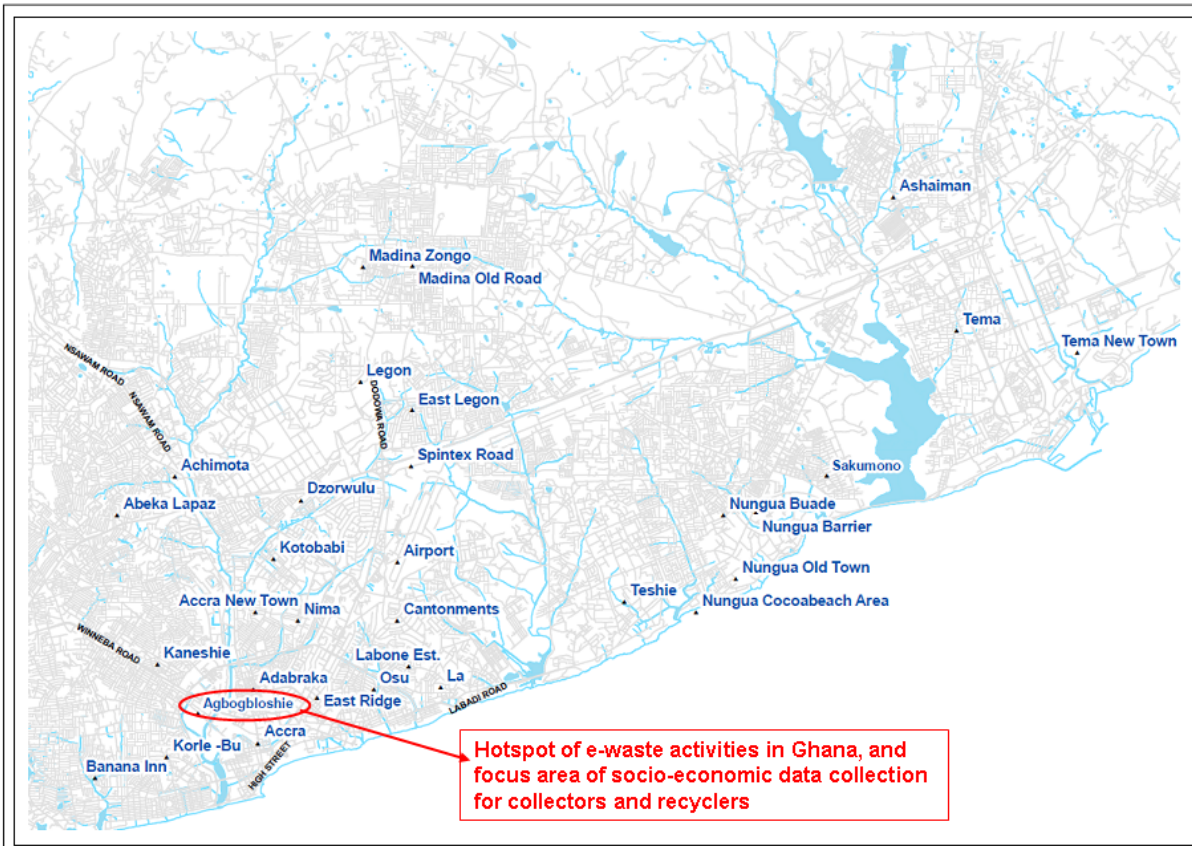


Figure 1 Map of Accra showing the areas of data collection for the socio-economic assessment

In total, 70 interviews were conducted to generate information on socio-economic impacts of the refurbishing and e-waste recycling sector in Ghana. The interviews with collectors (scavengers) and recyclers were conducted primarily at the Agbogbloshie metal scrap yard, a major hotspot for e-waste activities in Accra. The interviews with refurbishers were conducted at various locations (places indicated in figure 1) in Accra as these businesses are not located at a central place, but rather scattered all over the city of Accra.

Additionally, interviews with local experts, as for instance EPA Ghana, Accra Metropolitan Assembly (AMA), the Repairers Association (GESTA) and president of the Agbogbloshie Scrap Dealers Association, were carried out to complete, validate and cross-check the primary data. Especially, data quality was cross-checked and improved by Mr. Michael Anane, journalist and pioneer in the field of assessing and reporting social and environmental impacts of e-waste activities in Ghana.

The product scope was kept in line with the product scope of the component 3 of the SBC E-Waste Africa project, i.e. socio-economic assessment of the e-waste sector in Nigeria. This was done to ensure a comparative analysis of two major hotspots of e-waste activities in West Africa. The project scope for the study was defined to include the following e-waste categories:

1. Large household appliances:
 - refrigerators (cooling and freezing),
 - air conditioners.
2. Small household appliances:
 - irons,
 - kettles.
3. IT and telecommunication equipment:
 - desktop-PCs & notebook-PCs,
 - CRT-monitors & flat screen-monitors,
 - mobile phones.
4. Consumer equipment:
 - TVs,
 - radios (including hi-fi-systems).

2.2 Analysis and feasibility of recycling technologies

The section on the feasibility of international e-waste recycling co-operations between Ghana and Europe is based on the analysis and comparison of the presently applied recycling technologies and other alternative recycling technologies and management paths. This is performed with a view to analyse the applicability of these recycling technologies in the Ghanaian context on the basis of their specific environmental benefits and practical considerations. Furthermore, it was analysed, which recycling steps can be carried out locally within Ghana and which steps have to make use of an international division of labour, namely the export of certain fractions or substances to state-of-the-art treatment facilities. This kind of exports are only considered if no other suitable processing seems possible in domestic plants or would require investments and treatment volumes that would be clearly oversized for the current waste management structure and volumes.

On the basis of the best applicable recycling technologies, the economic, environmental and social improvement potentials are analysed and quantified as far as possible. With regards to social improvement potential, special emphasis is on health and safety issues related to the best applicable technologies, as well as its estimated labour intensities.

Drawing from this analysis, possible business models are sketched that could help to tap the described improvement potentials. Thereby, special emphasis is on the possible role of the informal sector and on defining strategies to include the informal sector in future e-waste implementation strategies instead of creating competition between a formalised and non-formalised recycling industry.

The analysis is conducted for three key product groups, namely desktop computers, CRT-devices and refrigerators and freezers. The selection of product groups is based the following criteria:

- The product group constitutes an important share of the total e-waste volume in Ghana;
- The end-of-life phase is of particular environmental concern;
- Improved end-of-life management can serve as model for the management of other product groups with similar characteristics.

The results of this criteria analysis are presented at the beginning of each product group analysis in the section “relevance for Ghana”.

3 Results of socio-economic assessment

3.1 Overview on the informal e-waste management system in Accra, Ghana

In Ghana, e-waste collection and recycling is almost entirely managed by the informal sector. The economic motivation behind e-waste recycling in Ghana is the possibility to recover metals, such as aluminium, copper and iron / steel using simple tools, such as hammers, chisels, stones etc. Often, fire is used to burn cables and wires to recover copper. Wet chemical leaching processes, often associated with the recovery of precious metals from printed wiring boards (PWB) have not been observed in Ghana. However, separation, collection and trade of PWBs from Ghana to Asia are happening at an increasing pace.

Access to instant cash as a result of sale of recovered metals, trade of precious metal containing components to Asia and low-level of skills required to carry out material recovery operations, have made e-waste recycling an attractive economic activity for the poorer strata of the Ghanaian society. Mostly, people from the poor northern part of the country, a region facing chronic food insecurity, have, therefore, found engagement in the e-waste recycling business to be a more reliable livelihood strategy, albeit severe environmental and health hazards associated with it. Thus, a large section of these people have moved to the city of Accra, the capital of Ghana and one of the major centres of e-waste generation in the country, and settled in and around the area of Agbogbloshie. Hence, Agbogbloshie has become a central location of e-waste recycling activities in Ghana. Thereby, it has to be noted that the Agbogbloshie metal scrap yard is also a hub for scrap metals from various other sources than e-waste. This also includes waste cars and waste lead-acid batteries. Agbogbloshie is also the centre of a broad network of e-waste and scrap metal collectors searching the city Accra for metal containing wastes.

On the other hand, a large number of refurbishing and repair operations for electric and electronic products – in few cases, also belonging to formal businesses – are scattered all around the city of Accra. A large section of the refurbishing operations can be found near the port of Tema as many refurbishing units have close business linkages with importers and retailers of second hand electrical and electronic goods, also located near the Tema port. In many cases, refurbishing and importing businesses were also found to lie in one hand.

The mass flow chart, as illustrated in the following figure, shows the flow of electrical and electronic products between different actors involved in refurbishing and e-waste recycling chain in Ghana. The dotted line in the mass flow chart indicates the scope of the socio-economic study:

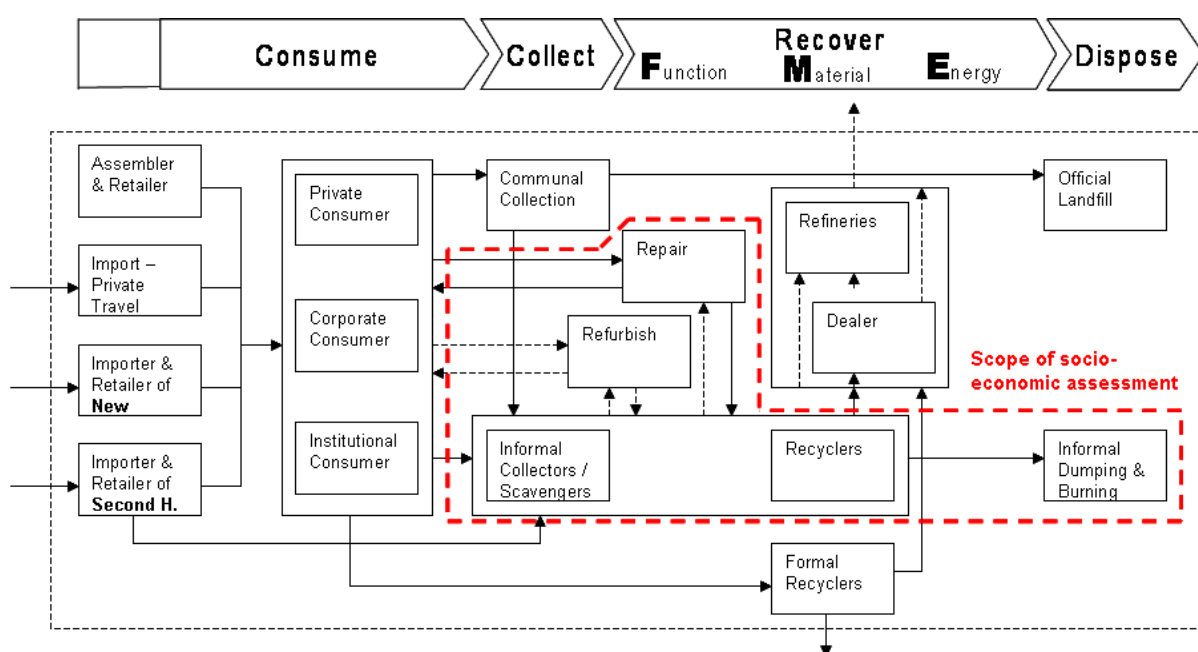


Figure 2 Mass flow chart of the refurbishing and e-waste recycling sector in Ghana

The scope of this study, i.e. socio-economic assessment of the informal refurbishing and e-waste recycling sector in Ghana, comprises following stages: collection, refurbishing / repair, recycling (involving dismantling, also burning) and final disposal⁷. The primary data collection for the socio-economic assessment took place for the following e-waste actors: (1) Informal collectors, also known as scavengers; (2) Refurbishers or repairers; (3) Recyclers

Informal collectors refer to those e-waste actors who execute door-to-door collection of metal containing wastes, including e-waste from private, corporate and institutional consumers. In this study, this group is generally referred to as collectors. Generally, collectors pay a little

⁷ Generally, collectors and recyclers can be found at the informal dumping and burning sites. Therefore, the analysis of informal dumping and burning sites corresponds to that of collectors and recyclers.

amount of money to the consumers to buy e-waste. For instance, a collector pays about US\$ 1.0 to US\$ 2.5 for an obsolete desktop PC, and about US\$ 1.5 to US\$ 5.0 for an obsolete refrigerator to the consumer. Often, collectors do not pay anything for these items as they find them dumped at street corners and even at the dumpsites by importers. In many cases, collectors also perform the function of dismantling and metal recovery themselves, as for instance, by burning cables and wires to recover copper.

Refurbishers or repairers transform old and/ or non-functioning EEE into second-hand and functioning EEE either by replacing or repairing defective components and/ or by performing cleaning and repair activities in order to make second hand EEE appealing to the customers. Although there is sometimes a distinction made between refurbishers and repairers, the boundary between the two groups cannot be drawn exactly. In this study, this group is generally referred to as refurbishers. A basic second hand desktop PC in Ghana costs between US\$ 60 to US\$ 100, a second hand cooling & freezing equipment between US\$ 140 and US\$ 180.

Recyclers in Ghana disassemble obsolete e-waste to recover metals, such as aluminium, copper and iron. While some recyclers are specialised on e-waste recycling, others engage in the recycling of various types of metal containing wastes. Some recyclers also engage in the open incineration of cables and other plastic parts in order to liberate copper and other metals. In few cases, recyclers deal directly with end-processing units, such as remelters and refineries, for selling the recovered metals. In many cases, middle-men are responsible for collection of recovered fractions from the recyclers, and bringing them to end processing units. During the primary data collection, recyclers reported of getting following (average) prices for the recovered fractions: Steel/iron – US\$ 0.46 per kg, aluminium – US\$ 1.07 per kg, copper – US\$ 4.6 per kg.

In the following sections socio-economic impacts of refurbishing and e-waste recycling activities on workers, local communities and society are described in detail.

3.2 Impacts on workers

3.2.1 Safe and healthy working conditions

The e-waste recycling industry in Ghana is widely associated with severe health and safety risks for workers involved in this sector (Brigden et al. 2008). These risks emerge primarily due to improper and crude recycling techniques used for the recovery of raw materials, as for instance, open incineration of cables and wires to recover copper. Also, fractions such as low-grade printed wiring boards (PWB) are incinerated to reduce the e-waste volumes⁸.

⁸ Some interviewees mentioned that occasionally traders of Asian origin come to purchase printed wiring boards. However, the mode of operation of the interviewees is solely demand-based, and hence the collection

Often, insulating foam, primarily polyurethane (PUR), from obsolete refrigerators⁹, and automobile tyres, are used as co-fuels to sustain the fires used for burning cooling grills of air conditioners.



Photo 1 Burning of cables at Agbogbloshie Metal Scrap Yard, Accra (Source: Öko-Institut 2010)

Brigden et al. (2008) tested the soil and ash samples at the e-waste burning sites in the Agbogbloshie scrap yard, and proved the deposition of exorbitantly high concentrations of toxic metals, such as lead and cadmium, and halogenated chemicals, such as phthalates¹⁰, polybrominated diphenyl ethers (PBDEs)¹¹ etc. While exposure to lead fumes or dust is known to cause multiple disorders, including neurological, cardiovascular and gastrointestinal

of printed wiring boards is not done on regular basis, but only when a ready purchaser is available to ensure instant cash. Interviewees reported of getting between US\$ 1 and US\$ 4.5 per kg of printed wiring boards.

⁹ Use of PUR-foam as a co-fuel during the incineration of cables and wires could release ozone depleting substances, such as chlorofluorocarbons (CFCs), commonly used as foaming agent in older refrigerators, into the atmosphere (see chapter 4.3).

¹⁰ Used as plasticizers or softeners in plastics, especially PVC.

¹¹ Used as a flame retardant in plastic components of electronic equipment.

diseases (Haefliger et al. 2009), exposure to cadmium fumes or dust leads to malfunctioning of kidneys (Hellstrom et al. 2001) and respiratory system (WHO 1992), and possibly lung cancer (DHSS 2005). On the other hand, even in Europe, workers in electronics recycling facilities have higher blood levels of PBDEs than other workers (Brigden et al. 2008; Sjödin et al. 2003; Sjödin et al. 2001). Consequently, it is assumed that in the absence of protective gear and other workplace standards, the levels of PBDEs in the blood of the recycling workers in Ghana would be much higher. Exposures to PBDEs have been known to cause endocrine disruptive properties (Legler & Brouwer 2003) and neurobehavioral disturbances in animals, such as abnormal brain development (Qu et al. 2007; Kuriyama et al. 2005).

Apart from open incineration, inappropriate dismantling techniques to recover metals such as copper, aluminium and iron, also represent enormous risks to the workers. For example, breaking of CRT-monitors using stones, hammers, heavy metal rods and chisels, to recover copper, steel and plastic casings, could result in the inhalation of hazardous cadmium dust and other pollutants by the workers.



Photo 2 Collectors transporting scrap metal to a dismantling site in Accra (Source: Öko-Institut 2010)

While the above mentioned health related risks are representative for the recyclers working on metal scrap yards, the informal e-waste collectors face negligible health risks from the

waste itself, unless they are themselves involved in dismantling and metal recovery process as well. However, a job of an informal e-waste collector involves about 10–12 hours of pulling of handcarts, made from boards and old car axles, in order to transport obsolete EEE from e-waste shops and warehouses from different parts of the city to the dismantling site or scrap yard. Often such a rigorous activity leads to spinal injuries and back pains due to lifting and transportation of heavy appliances, and consequently to a relatively short career spanning not more than 6–7 years.

Similarly, the magnitude of health risks faced by refurbishers and repairers of EEE is much smaller compared to recyclers. Refurbishers and repairers make use of simple tools, such as screwdrivers, pliers, electrical soldering machines, hammer etc. either in order to replace a defective part with a new one or to repair the existing parts to generate a saleable good. Often, refurbishing and repairing activities make use of natural daylight and aeration for the most part of the operation.



Photo 3 Refurbishing activity in a shop in Accra (Source: Öko-Institut 2010)

Apart from that, many refurbishers reported the inhalation of fumes during electrical soldering operations as a major health threat. As metallic lead had been used in electrical solder, commonly as an alloy with tin, it is estimated that refurbishers and repairers could also suffer

from lead-borne diseases. Many workers complained of mucus and pain in the eyes, which probably can be attributed to the fumes from the soldering activities. Furthermore, electrical shocks while repairing and refurbishing activities, was reported to be another safety related issue.

Discussions with various workers and the Agbogbloshie Scrap Dealer Association revealed that refurbishers and recyclers are aware of existing health risks as they complain of headaches, respiratory problems, chest pains, rashes, burns and cuts. Attempts to encourage them to use donated inhalation masks have not been effective as they complain that they do not feel comfortable wearing the masks or hand gloves.

3.2.2 Freedom of association and right to collective bargaining

Ghana ratified the ILO fundamental conventions C87 on Freedom of Association and Protection of the Right to Organise Convention in 1965, and C98 on Right to Organise and Collective Bargaining in 1959¹². E-waste recycling in Ghana is organised into numerous small and informal enterprises. As a major section of the enterprises or rather people is involved in the informal sector, the e-waste recycling sector does not feature formalized workers' participation mechanisms. Similarly, in case of refurbishing businesses, experts opinion suggest that more than 80% of enterprises/ people involved in the refurbishing sector in Ghana are not registered with their respective local governmental bodies or metropolitan assemblies (Pwamang 2010). Nevertheless, some form of informal collective bodies, such as the Agbogbloshie Scrap Dealer Association do exist in Ghana. The Agbogbloshie Scrap Dealer Association boasts about 3,000 members in the Accra metropolitan area. This body also has a president and a secretary. Field observations suggest that the president and the secretary only have a marginal influence on their members. Also, for the refurbishers and repairers, a formal association known as GESTA with about 500 members, was found to be active in Ghana. Additionally, there is a national workshop owners association, known as NARWOA, for businesses engaged in the sale and repair of refrigerators, freezers and air-conditioners.

3.2.3 Equality of opportunity and treatment and fair interaction

Ghana ratified ILO fundamental conventions C100 on Equal Remuneration in 1968, and C111 on Discrimination (Employment and Occupation) in 1961.

The e-waste recycling sector in Ghana is dominated by male workers. However, many young girls of ages between 9 and 12 were also observed working as collectors at the Agbogbloshie dumpsite. The collection and recycling activities in the e-waste recycling sector entail mostly workers from the northern part of Ghana. Thus, people from the same region are generally preferred when it comes to providing new employment opportunities. The

¹² Source: ILO Website: <http://www.ilo.org/ilolex/english/convdisp1.htm>

refurbishing and repair activities are also dominated by men. However, few jobs, mostly related to the sales of refurbished equipments or finance management, were observed to be filled by females.

There is little information available on hierarchies or disciplinary practices. Also, systematic discriminatory practices could not be observed as well, probably due to small-scale and/or family based entities. Often, owners of refurbishing enterprises (formal and informal) employ interns for certain tasks. Such tasks range from learning and conducting technical work to typical household tasks (cleaning, washing etc). Generally, interns are not provided with any remuneration. On the contrary, interns are supposed to pay the owners occasionally a “token” charge for providing the opportunity to learn technical skills. In majority of the cases, interns are provided with shelter and food by the owners.

3.2.4 Forced labour

There are no reports on forced labour within the refurbishing and e-waste recycling industry in Ghana. Ghana ratified the ILO fundamental conventions C29 on Forced Labour in 1957, and C105 on Abolition of Forced Labour in 1958.

3.2.5 Child labour

Ghana ratified the ILO fundamental convention C182 on Worst Forms of Child Labour not until year 2000. The other ILO convention related to child labour, i.e. C138 on Minimum Age, has not yet been ratified by Ghana.

Under the convention C138, the general minimum age for admission to employment or work is 15 years (13 for light work). Additionally, there is the possibility of setting the general minimum age at 14 (12 for light work) in regions where the economy and educational facilities are insufficiently developed. Furthermore, minimum age for hazardous work has been set at 18 years (16 years under the condition that *“the health, safety and morals of the young persons concerned are fully protected and that the young persons have received adequate specific instruction or vocational training in the relevant branch of activity”* – Article 3, paragraph 3).

However, Article 3, paragraph 1 of the convention C138 specifically states that *“the minimum age for admission to any type of employment or work which by its nature or the circumstances in which it is carried out is likely to jeopardise the health, safety or morals of young persons shall not be less than 18 years”*. Considering severe health hazards associated with the e-waste recycling activities, as also described in the section “Safe and healthy working conditions” (3.2.1) of this report, inappropriate e-waste recycling activities carried out without adequate instruction, training and sensitization, would be classified as hazardous work.

Furthermore, under the ILO Worst Forms of Child Labour Convention No. 182, the term child applies to all persons under the age of 18. The worst forms of child labour comprises all forms of slavery or practices similar to slavery, such as sale and trafficking of children, debt bondage, forced or compulsory labour, use, procuring or offering of a child for prostitution, drug trafficking etc. Article 3, paragraph 4 includes “*work which, by its nature or the circumstances in which it is carried out, is likely to harm the health, safety or morals of children*”.



Photo 4 An example of child labour in e-waste sector in Accra (Source: Öko-Institut 2010)

Own field observations and Greenpeace reports "*Chemical contamination at e-waste recycling and disposal sites in Accra and Koforidua, Ghana*" and "*Poisoning the poor – Electronic waste in Ghana*" confirmed the employment of children, mostly boys, sometimes as young as 5 years old and mostly between 11 and 18 years (Brigden et al. 2008), in the informal e-waste recycling sector in Ghana. However, also young girls of ages between 9 and 12 were also observed working as collectors, and in many cases as vendors of water sachets, at the Agbogbloshie. Most of the recyclers and collectors are aged between 14 and 40 years. Average recyclers and informal collectors are in their early twenties.

Children were seen to be involved primarily in burning activities, but also in manual dismantling of hazardous nature, such as that involved in the recovery of copper containing deflection coils in the CRT monitors. Health impacts on children involved in e-waste recycling are described in sections “Safe and healthy working conditions” (3.2.1) and “Safe and healthy living conditions” (3.3.1). It should however be pointed out that the children are generally self employed and seldom work for any superior.

3.2.6 Remuneration

Due to the informal nature of the e-waste recycling sector in Ghana, official figures on the income of the workers are not available. Most of the workers are remunerated by their employees on the basis of output generated per day, and not on the basis of a fixed monthly salary. Therefore, workers of the informal e-waste recycling sector in Ghana can be categorized among the so called daily labourers.

In the case of collectors, who solely focus on collection activities, and not on dismantling and recovery of materials, the income depends upon the amount of e-waste collected from different parts of the city and subsequently sold to recyclers. The assessment of the socio-economic data in this study revealed that a collector earns on an average between GHS 100 to 200 (US\$ 70 to 140)¹³ per month, depending upon the total amount of e-waste collected. This income actually reflects the profit margin generated by a collector at the end of the month, i.e. the investment for buying obsolete equipments deducted from the money earned after reselling them to recyclers. In worst cases, collectors are not able to collect any obsolete equipment in the whole day, and hence end up earning nothing after a whole day’s work. According to local experts, incomes of children between 5 and 14 years, could lie as low as US\$ 20 per month.

In the case of recyclers, the data suggests that the average income or rather profit of a recycler lies between GHS 250 to 400 (US\$ 175 to 285) per month. The income is calculated by deducting the amount of money paid to collectors for bringing in e-waste from the money earned after selling recovered material, such as copper, aluminium and iron, but also PWBs, to dealers or end-processing units. Other sources indicate that incomes of recyclers as well as of collectors could lie below US\$ 60 in most cases (Anane 2010).

Similarly, the average income or profit of a refurbisher was calculated to be between GHS 275 to 350 (US\$ 190 to 250) per month. However, in some cases, interviewees suggested of a low income of less than US\$ 100 per month in the refurbishing business (Anane 2010). It has to be noted that in many cases, the incomes stated above are used to partially or fully

¹³ 1 GHS = 0,71153 US\$ (www.oanda.com; Interbank rate, 01.01.2010–01.06.2010)

sustain a family of about 6 people (considering a Total Fertility Rate, TFR¹⁴, of 4.0 for the urban regions in Ghana).

It is necessary to interpret the above mentioned income data in the whole context of the Ghanaian economy. The Ghanaian economy has grown at an average annual rate of 4.5 percent over the past two decades, indicated by a GDP growth of 6.3 per cent in 2007 (FAO 2010). The GDP per capita (current US\$) rose dramatically from US\$ 255 in year 2000 to US\$ 713 in 2008 (The World Bank Group 2010). The benefits of economic progress are evident in the fact that national poverty rates have been cut almost to half, from approximately 51.7 per cent in 1991–1992 to 28.5 per cent in 2005–2006. Poverty decreased by about 17 percentage points in urban areas and by 24 points in rural areas (FAO 2010). In terms of poverty head count ratio regarding purchasing power parity (PPP), about 30% of the population of Ghana lived with less than US\$ 1.25 per day in 2006–2007, whereas about 54% of the total population survived with less than US\$ 2 per day in 2006–2007. Furthermore, about 29% of the total population in Ghana lives below the national poverty line (The World Bank Group 2010; UNDP 2009a).

The income data for the workers of informal e-waste recycling sector suggest that collectors represent the most vulnerable group in terms of low income, as most of them possess an income of only between US\$ 2.3 to 4.6 per day. However, the incomes of collectors seem to increase substantially in case of their vertical integration within the e-waste value chain. Specifically, it implies that collectors who also engage in practices related to dismantling and recovery of materials, i.e. recycling, have higher incomes. Recyclers earn about US\$ 5.8 to 9.5 per day, and refurbishers about US\$ 6.3 to 8.3 per day. Therefore, the data implies that if the Total Fertility Rate (TFR) of 4.0 for Ghana is considered (which would mean at least 6 people in a household), most of the workers engaged in informal e-waste recycling sector continue to live under the internationally and nationally defined poverty lines. The table below summarizes the remuneration of collectors, refurbishers and recyclers.

Table 3 Remuneration (in US\$) for the people engaged in refurbishing and e-waste recycling business in Ghana (Source: Own calculations)

	Refurbishers	Collectors	Recyclers
Remuneration per day (in US\$)	(3.3) 6.3–8.3	(2.0) 2.3–4.6	(2.0) 5.8–9.5
Remuneration per month (in US\$)	(100) 190–250	(60) 70–140	(60) 175–285

* Figures in brackets indicate the information from Anane 2010

¹⁴ Total Fertility Rate (TFR) in Ghana means that a woman who is at the beginning of her childbearing years will give birth to an average of 4.0 children by the end of her reproductive period if fertility levels remain constant at the level observed in the three-year period before the 2008 Ghana Demographic and Health Survey (GDHS) (GSS 2008).

This is a significant revelation, especially considering two important facts: (1) about 11% of the total urban population in Ghana¹⁵ lives below poverty line (The World Bank Group 2010), and (2) most of the workers of informal e-waste recycling sector originate from the northern part of the country where majority of the poor facing chronic food insecurity live (FAO 2010). Thus, even though engaging in informal e-waste recycling sector does not necessarily ensure higher incomes, the workers engaged in this sector have access to regular income in the form of a rapid cash flow – an aspect which is largely absent in agriculture-driven households in northern Ghana.

It has to be underlined that the above mentioned data and interpretations are solely based on calculated incomes as a result of productive economic activity. Indirect costs or externalities, as for instance inability to work in certain periods of illnesses or occurrence of costs related to the treatment of health related problems, common in the e-waste recycling sector, have not been considered. Other indices, such as Human Development Index (HDI), as included in United Nations Development Program's Human Development Reports¹⁶, might be better suited to measure true human well-being of the people of the refurbishing and e-waste recycling sector. HDI is a comparative measure that considers life expectancy, literacy, education and standards of living for countries worldwide. Out of 177 countries, Ghana stands at 152nd place on the HDI, indicating only a medium human development status among developing countries.

3.2.7 Working hours

There are several conventions of the International Labour Organization (ILO) that deal with the issue of working hours, overtime, overtime compensation and rest periods: C1 – Hours of Work (Industry) Convention, 1919, C30 – Hours of Work (Commerce and Offices), Convention, 1930, C106 – Weekly Rest (Commerce and Offices) Convention, 1957, C14 – Weekly Rest (Industry) Convention, 1921. These conventions demand that workers shall not, on a regular basis, be required to work in excess of 48 hours per week and shall be provided with at least one day off for every 7 day period on average. Overtime shall be voluntary, shall not exceed 12 hours per week, shall not be demanded on a regular basis and shall always be compensated at a premium rate, generally one and one-quarter times the regular rate. Although Ghana has been a signatory to all the above mentioned conventions, their implementation in the refurbishing and e-waste recycling industry in Ghana is difficult due to its informal character.

¹⁵ 48% of total population of Ghana lives in urban areas. Total population of Ghana is about 24 million (The World Bank Group 2010).

¹⁶ Human Development Report 2009: Overcoming Barriers – Human Mobility and Development.
Website: http://hdr.undp.org/en/media/HDR_2009_EN_Complete.pdf

Due to the informal nature of the e-waste recycling sector in Ghana, most of the workers do not have any fixed working time in terms of hours per day or per week. Recyclers in the Agbogbloshie scrap yard were found to work between 10–12 hours per day, even on weekends. This implies 30 work days or 300 to 360 work hours per month. They reported to take a day off occasionally in cases of health or family related matters albeit without getting paid for those specific days. Furthermore, e-waste recycling activities are not organised in strict production lines, so that individual workers may arrange working hours and rest periods to their specific needs (Manhart 2007). These rest periods or breaks rarely exceed 30 minutes per day. Similarly, collectors were also found to work for about 10–12 hours per day, i.e. 300 to 360 hours per month. Collectors who also engage in dismantling / recycling activities generally try to reserve the latter part of the working day, mostly after 4 PM, to dismantling / recycling. This implies that they spend about 6–8 hours per day with the collection of e-waste from various parts of the town, and 2–4 hours per day for dismantling / recycling. The refurbishing and repair part of the value chain seems to have more regular working hours, generally ranging from 8–10 hours per day. Refurbishers also reported to take a weekend, mostly Sundays, as a holiday. Furthermore, most of the interviewees mentioned to be able to have holidays on Ghanaian national holidays. This fact is related especially to the aspect of sales of refurbished and repaired EEE to private and corporate consumers and pre-defined opening and closing times for the shops in residential and commercial areas in Ghana. Furthermore, mid-day meal breaks of 30 minutes to 1 hour per day were found to be prevalent. Therefore, monthly working hours for refurbishers can be assumed to lie somewhere between 210 to 260 hours. The following table summarizes the findings on the working hours:

Table 4 Working hours for the people engaged in refurbishing and e-waste recycling business in Ghana
(Source: Own calculations)

	Refurbishers	Collectors	Recyclers
Working hours per day	8–10	10–12	10–12
Working hours per month	210–260	300–360	300–360

As a comparison, reports on labour conditions of workers employed in the computer manufacturing in China, have revealed similar trends. In computer manufacturing in China, workers were found to work between 10–12 hours per day, 6–7 days per week, which implies about 80 to 200 overtime hours per month (SACOM 2008).

3.2.8 Employment security

Only a very minor section of workers in the refurbishing and e-waste recycling sector holds formal labour contracts. Such workers were found to be engaged only in some high-end refurbishing businesses. In the e-waste recycling and collection part, none of the inter-

viewees had formal labour contracts. The employment turn-over in the e-waste recycling sector was observed to be very high, ranging between 3–7 years, primarily because of low incomes, but also due to lack of employment security.

However, employment perspectives for workers in refurbishing and e-waste recycling business can be assumed to be positive due to following reasons:

- The EEE and e-waste volume in Ghana is growing steadily
- Labour intensity continues to be high in the informal refurbishing and e-waste recycling structures (Widmer et al. 2007).

Nevertheless, there are recent attempts to formalize certain e-waste recycling systems in Ghana (see chapter 4.3) which includes the reform of the established collection, disassembly and management of hazardous substances. Such a step could lead to a vast replacement of the existing e-waste recycling structures, hence endangering employment securities for many people working in this sector.

3.2.9 Social security

Due to the informal character of the sector most employees of the refurbishing and e-waste recycling sector are not covered by health and unemployment insurances, and old age pensions schemes. Nevertheless, many interviewees emphasized the contribution of widespread family structures in e-waste recycling businesses in Ghana. As most of workers in the e-waste recycling sector have their origin in northern Ghana, they are keen on employing friends and relatives, sometimes as apprentices, from the same region and communities. In such cases, many interviewees reported of availing certain benefits in cases of emergencies, such as medical help, from their employers. These benefits range from financial and material help to providing holidays, albeit unpaid, to the workers.

3.2.10 Professional development

Possibilities of any kind of professional development have hardly been explored for the workers of the informal e-waste recycling sector in Ghana. Often, owners of refurbishing enterprises employ interns for certain tasks. Such tasks range from learning and conducting technical work to typical household tasks (cleaning, washing etc). Generally, interns are not provided with any remuneration. On the contrary, interns are supposed to pay the owners occasionally a “token” charge for providing the opportunity to learn technical skills. In majority of the cases, interns are provided with shelter and food by the owners.

The current nature of jobs in the refurbishing and e-waste recycling sector can easily be fulfilled by low-skilled workers.¹⁷ During the interviews of recyclers, collectors and refurb-

¹⁷ Generally, workers of the e-waste recycling sector in Ghana have a very low education level as a majority of the interviewees were found to be either illiterate or at the most with a primary or Junior Secondary School

bishers in Greater Accra region, it became obvious that although most of the workers were generally aware of the hazardous nature of improper e-waste recycling activities, they did not have any specific solutions against the problem. Due to frequent health related problems among the workers of the refurbishing and e-waste recycling sector, the interviewees were found to be principally interested in learning new skills and upgrading technology and know-how needed to raise their standards of work and living.

3.2.11 Job satisfaction

Surveys related to job satisfaction are generally based on subjective opinions of the workers which can vary significantly even in similar working conditions. During the interviews of the workers of the refurbishing and e-waste recycling sector, it was observed that workers were not overly positive about their working conditions, but still indicated a certain level of satisfaction with their incomes. One of the most cited reasons was the ability to send remittances regularly to their families in the northern part of Ghana. Many interviewees, however, emphasized that they have to cut their costs, for instance by avoiding costs related to housing and education, in order to save ample money to send to their families. Interviewees mentioned that engaging in the refurbishing and e-waste recycling business provides them access to rapid cash flow, which was often not the case in their traditional modes of livelihoods, such as agriculture.

In terms of employment turnover rates, the data suggests high rates ranging between 3 to 7 years. This could be attributed to the fact that e-waste recycling business is associated with severe health problems, rigorous working conditions, poor remuneration and no employment and social security. However, many workers also seek to set up their own businesses after gathering enough experience and skills of refurbishing and e-waste recycling.

3.3 Impacts on local communities

3.3.1 Safe and healthy living conditions

The Greenpeace studies „*Chemical contamination at e-waste recycling and disposal sites in Accra and Koforidua, Ghana*“ and „*Poisoning the poor – Electronic waste in Ghana*“ were the first scientific studies related to occupational and residential hazards as a result of improper e-waste recycling and disposal in Ghana. The authors of the studies collected soil/ ash samples at burning sites in Agbogbloshie and Koforidua, soil samples below the broken CRT glass within a disposal area in Agbogbloshie and sediment samples in the lagoon adjacent to disposal and burning sites in Agbogbloshie, and tested them for the concentration of toxic metals, organic chemicals and other hazardous compounds, such as dioxins and furans

(JSS) level. Only in few cases in the refurbishing sector, a negligible minority of the workers had a university degree or comparable private training in repair of EEE.

(PCDD/Fs). Currently, the US Blacksmith Institute, in cooperation with local research partners, is collection blood and urine samples of the people engaged in and/ or living around the Agbogbloshie metal scrap yard. However, results of this survey have not yet been published.

Results of the Greenpeace studies confirmed the presence of "numerous toxic and persistent organic chemical pollutants, as well as very high levels of many toxic metals, the majority of which are either known to be used in electronic devices, or are likely to be formed during the open burning of materials used in such devices" (Brigden et al. 2008). The concentrations of copper, lead, zinc and tin were found to be in the magnitude of over one hundred times typical background levels (Brigden et al. 2008). It is known that children, due to their hand-to-mouth behaviour, are one of the most vulnerable groups in areas where soils and dusts are contaminated with lead (Haefliger et al. 2009; Malcoe et al. 2002). For instance, deaths of 18 children between November 2007 and March 2008 due to mass lead intoxication from informal used lead-acid battery recycling in Senegal, was attributed to inhalation and ingestion of soil and dust contaminated with lead. In this case, homes and soils in surrounding areas of lead-acid recycling activities were found to be heavily contaminated with lead, indoors up to 14,000 mg/kg and outdoors up to 302,000 mg/kg (Haefliger et al. 2009).



Photo 5 Recovery of lead at the Agbogbloshie Metal Scrap Yard, Accra (Source: Öko-Institut 2010)

The concentration of lead in the soil and ash samples collected in Agbogbloshie and Koforidua were found to be as high as 5,510 mg/kg dry weight. Although lead concentrations in Agbogbloshie and Koforidua are lower than those measured in areas of lead-acid recycling activities in Senegal, they clearly exceed the limits set for residential and industrial areas. For instance, French recommendations for lead limits are set at 400 mg/kg and 2000 mg/kg for residential and industrial areas respectively (Laperche et al. 2004). Exposure to lead dust or fumes leads to the underdevelopment of brain in children, hence causing intellectual impairment (Haefliger et al. 2009; Brigden et al. 2008). Apart from that, lead is known to cause a wide range of disorders, such as “damage to the nervous system and blood system, impacts on the kidneys and on reproduction” (Brigden et al. 2008).

Similarly, negative health impacts of flame retardants, such as PBDEs, could also occur, not only through direct exposure, but also through food contamination (Harrad et al. 2004). For example, in China high levels of PBDEs have been reported in the blood of local residents around e-waste recycling activities (Bi et al. 2007). PBDEs have been known to cause abnormal brain development in animals (Eriksson et al. 2002), endocrine disruptive

properties (Legler & Brouwer 2003) and anomalies in the immune system (Birnbaum & Staskal 2004).

Further, incineration of PBDE containing or PVC coated cables and wires, could produce dioxins and furans (PCCD/Fs) (Gullet et al. 2007; Hedman et al. 2005). Brigden et al. (2008) measured 359 pg/g of toxicity equivalent value (TEQ) for PCCDs and 629 pg/g TEQ for PCCFs in the sediment samples of the lagoon adjacent to Agbogbloshie. The background levels of PCCD/Fs in soils and sediment have not yet been defined in Ghana so far, but the above mentioned PCCD/Fs values indicate extremely high contamination.



Photo 6 E-waste adjacent to the lagoon at Agbogbloshie, Accra (Source: Öko-Institut 2010)

Commonly, in unpolluted or lightly polluted areas, including urban and industrial soils in other countries, the values are below 1 pg/g TEQ and rarely above 10 pg/g TEQ (Zhu et al. 2008). According to a recent survey done by EMPA, the total annual dioxin emissions from cable incineration in Greater Accra region were estimated to be about 5 g (EMPA 2010). Compared to the European dioxin air emission inventory for 2005 (EU15 + Norway + Switzerland) this equals to 0.25%–0.5% of total dioxin emissions, 2.5%–5% of dioxin

emissions from municipal waste incineration and 15%–25% of dioxin emissions from industrial waste incineration (EMPA 2010).

According to local residents, the lagoon used to be a common fishing ground for the local communities until some years ago. However, disposal and e-waste recycling activities near the lagoon have eliminated all kind of lives in the lagoon. Many interviewees reported that large quantities of unusable waste, such as broken CRT glass, is frequently dumped in the lagoon in order to avoid over-accumulation in the scrap yard, and also to prevent injuries to the workers. Moreover, it is expected that during rainy season when a major portion of the site is flooded, contaminated soil and dust from the burning sites is carried to the adjacently low-lying lagoons and also into the sea close by. Brigden et al. (2008) demonstrated that the lagoon sediment level is about 988 pg/g TEQ, which is defined as being indicative of serious contamination for soil and sediment in the Netherlands (NMHSPE 2000).

3.3.2 Human rights

There are no reports on the violation of human rights in the neighbourhood of refurbishing and e-waste recycling sites that were linked to the activities of the people involved in these businesses¹⁸.

However, in the past, residents of Agbogbloshie have been served with an eviction notice by the Accra Metropolitan Assembly (AMA) on the grounds of being responsible for the degeneration and pollution of the adjoining lagoons. For instance, an environment and social impact assessment conducted on the behalf of the Korle Lagoon Ecological Restoration Project (KLERP), urged the local government to declare the Agbogbloshie area as a national disaster site, and resettle the people (Du Plessis 2005). It is assumed that planned eviction strategies of the local government can be partially attributed to the role played by the informal e-waste recycling sector in terms of environmental degradation of the area. Only with support from organizations such as the Centre on Housing Rights and Evictions, the Centre for Public Interest Law and People's Dialogue on Human Settlements, the local residents could resist the implementation of forced eviction of the local government (Du Plessis 2005; COHRE 2004).

3.3.3 Indigenous rights

There are no recent reports on the violation of indigenous rights associated with the refurbishing and e-waste recycling activities in Ghana.

However, there has been a historical conflict with the Ga community, which considers Agbogbloshie to be their traditional living ground. There have been several protests and

¹⁸ Although severe health and safety hazards for workers and neighbouring communities may be regarded as violations of human rights, in this study these topics are covered in sections "Safe and healthy working conditions" (3.2.1) and "Safe and healthy living conditions" (3.3.1).

campaigns from the members of the Ga community urging the Ghanaian government to evict the people currently living in Agbogbloshie (Du Plessis 2005; COHRE 2004).

3.3.4 Community engagement

Mechanisms for the participation of local communities in terms of being informed about the consequences of refurbishing and e-waste recycling activities, and possibly influence decisions to be made which may affect the local environment, human health and well-being, are not in place. In Agbogbloshie scrap yard, a Scrap Dealer Association does exist, but it represents only the interests of its members, and was not found to approach neighbouring communities for a dialogue. Similarly, GESTA, the Repairers Association, was not found to be involved in community engagement mechanisms.

3.3.5 Socio-economic opportunities

As described in the sections “Remuneration” and “Job satisfaction” and later in section “Employment creation”, the great demand for low-skilled workers in the informal e-waste recycling industry in Ghana have opened up employment opportunities not only for workers from the north of Ghana, but also for other inhabitants of Agbogbloshie. While the quality of jobs is doubtful in most of the cases, primarily due to health and environmental concerns, these employment opportunities offer alternatives to agricultural work or widespread rural employment. According to the Food and Agricultural Organization of the United Nations (FAO), low productivity and poorly functioning markets for agricultural outputs are major causes of rural poverty in Ghana (FAO 2010). Comparatively, engaging in the e-waste recycling sector, workers have regular access to cash because of high demand of recovered materials, nationally¹⁹ and internationally^{20,21} and sufficient availability of e-waste inputs. Although fluctuation in international resource prices make workers of the e-waste recycling industry vulnerable in terms of economic stability, they have been found to prefer this sector over traditional modes of livelihoods, like agriculture. Moreover, engaging in e-waste recycling sector keeps them out of fear of urban unemployment. Importantly, many workers

¹⁹ See chapter 4.

²⁰ According to the European Aluminium Association (EAA) and the Organization of European Aluminium Refiners and Remelters (OEA), in 2004, approximately 11.4 million tons of aluminium were used for the production of fabricated goods in the EU. Primary aluminium production in the EU currently amounts to just 3 million tons. This in fact means that, without aluminium recycling, the EU would have to import about 8.4 million tons of primary and recycled aluminium to meet requirements. Primary aluminium production in the rest of Europe yields a further 2.2 million tons so, even if this figure were added to the equation, the EU would still depend considerably on aluminium imports. This dependence is substantially alleviated, however, by the recycling of aluminium (EAA/OEA 2010).

²¹ According to the International Copper Study Group (ICSG), the world refinery capacity utilization (primary and secondary refined production) for copper was about 81.1% in 2008, which actually implies that world copper refinery capacity still has some unfulfilled potential.

emphasized the value of sending remittances to their families on a regular basis as a result of employment in e-waste recycling sector. Many workers also mentioned the possibility of setting up their own small businesses after a few years of work.

According to COHRE (2004), there are at least four different socio-economic reasons behind the establishment and growth of Agbogbloshie:

- Migration from the north, as an outcome of tribal conflict and chronic food insecurity.
- Social downward movement in accommodation by those forced out of more expensive accommodation in Accra. This is due to the financial impact of the Structural Adjustment Programme that was initiated in the early 1980s.
- Spill-over of population associated with the size and growth of the adjacent market.
- Demand for land by those seeking economic and business opportunities in an area free from the bureaucratic constraints and high rentals that exist in the recognised formal market.

Similarly, demand for low-skilled workers in the refurbishing sector has also led to considerable employment opportunities for a large section of the society.

3.4 Impacts on society

3.4.1 Unjustifiable risks

The e-waste recycling industry in Ghana is not under the suspicion of directly generating unjustifiable risks for the whole Ghanaian society. Nevertheless, severe pollution from the current practices in material recovery and disposal is a significant long term risk that cannot be justified solely by economic development indicators. Especially, quantifiable externalities/external costs related to health hazards, premature mortality and environmental damage inflicted by improper e-waste recycling practices have not yet been sufficiently researched. This is especially the case for the major e-waste recycling centres like the Agbogbloshie scrap yard, which account for exorbitantly high concentrations of air and water pollutants and contaminated soils, both outdoor and indoors. Taking into account that burning of cables, wires and other plastic fractions of electronic devices is one of the major sources²² of dioxins and furans in Ghana (see section “Safe and healthy living conditions” (3.3.1)), it is obvious that the currently practiced e-waste recycling is the major source of these pollutants in Ghana.

In the field work of this study, unjustifiable risks as a result of refurbishing business were not identified.

²² According to EMPA (2010), about 10%–20% of cables are directly associated with e-waste. Apparently, end-of-life cars are another major source of copper cables.

3.4.2 Employment creation

Refurbishing and repair sector has been found to be partially formalized, with expert opinion suggesting that about 20% of all refurbishing/ repair businesses might be registered with the formal bodies (Pwamang 2010). Collection, disassembly, material recovery and final disposal take place almost only in the informal sector. This assumption was substantiated during the interviews where none of the collectors and recyclers mentioned to pay any kind of taxes to the local government. On the contrary, many refurbishing businesses suggested various kinds of taxes and insurances that are paid regularly. Some examples include: Internal Revenue Service (IRS), Value Added Tax (VAT), National Health Insurance (NHI), Social Security and National Insurance Trust (SSNIT) and local revenue to the Accra Metropolitan Authority (AMA).

Till date, there has not been any statistical information, either from government or non-government sources, on the number of people employed in the refurbishing and e-waste recycling sector in Ghana. The Labour Market Information System (LMIS) of the Ministry of Employment and Social Welfare, and the Ministry of Trade and Industry of Ghana do not provide any employment information based on business activity. Similarly, employment data for Ghana was not specified in international information sources, such as the Data Bank of the World Bank Group and the CIA – the World Factbook²³. Therefore, it is necessary to make certain assumptions based on interview data, expert opinion and other sources.

The most important cluster for e-waste recycling in Ghana is Agbogbloshie. According to the information from the President of the Agbogbloshie Scrap Dealers Association, the association boasts a membership of about 3,000. Expert opinion suggests that about half of the members, i.e. about 1,500 people, focus primarily on e-waste, while the other half on automobile dismantling and material recovery from automobiles. The primary socio-economic data collection revealed that on an average 3–4 workers are employed by one recycler²⁴. Considering that Agbogbloshie builds the major part of the (informal) recycling industry in Accra, and taking the number of people from Agbogbloshie Scrap Dealers Association as the calculation basis, it can be assumed that about 4,500 to 6,000 people are involved in informal e-waste collection and recycling operations in the region of Accra. Furthermore, on the basis of the survey from the Ghana Demographic and Health Survey (GDHS) 2008, which suggests the total fertility rate (TFR) of 4.0 for Ghana, it is assumed that about 27,000 to 36,000 people in Accra thrive partially or fully on e-waste collection and recycling operations.

²³ CIA – The World Factbook provides information on the total labour force in Ghana (10.33 Million in 2009, estimated) of which about 15% works in the industrial sector (CIA 2010).

²⁴ This also includes arrangements with collectors, who are given some money to go around the city to collect and buy e-waste.

In the refurbishing/repair sector, expert opinions suggest that most of the businesses are not registered with any local or national body. Hence, it is difficult to estimate the true number of refurbishing/repair businesses in Ghana. In such a scenario, an assumption can be made on the basis of the information provided by the Repairers Association (GESTA). According to GESTA, their membership lies at 500 members in Accra and Tema region. Considering the expert opinion that about 80% of the refurbishing/repair businesses are not registered with any local or national body (Pwamang 2010), it can be estimated that at least 2,500 refurbishing/repair businesses can be found scattered in the region of Accra and Tema, if not more. The socio-economic data revealed that each refurbishing/repair business employs between 4–6 employees, suggesting an employment creation for about 10,000 to 15,000 people in Accra. Again using the TFR of 4.0 provided by the GDHS 2008, it is assumed that at least 60,000 to 90,000 people thrive partially or fully on refurbishing/repair of EEE in the region of Accra. Thus, refurbishing and e-waste recycling sector employs about 14,500 to 21,000 people in Accra. In terms of household dependency, it is assumed that the refurbishing and e-waste recycling sector sustains about 87,000 to 126,000 people in the region of Accra.

Expert opinion suggests that refurbishing and e-waste recycling sector in Accra might account for 40%–60% of the total size of Ghanaian refurbishing and e-waste recycling activities. This would imply that about 6,300 to 9,600 people are engaged in e-waste collection and recycling operations in whole Ghana, in refurbishing/repair sector, the number lies at about 14,000 to 24,000. This implies that about 20,300 to 33,600 people are employed in refurbishing and e-waste recycling sector in Ghana, constituting about 0.19% to 0.32% of total labour force in Ghana²⁵. Using the TFR of 4.0 provided by the GDHS 2008, it is assumed that about 121,800 to 201,600 people in Ghana are partially or fully dependent on refurbishing and e-waste recycling operations. This represents about 1.04% to 1.72% of the total urban population in Ghana, or 0.50% to 0.82% of the total Ghanaian population²⁶. The following table summarizes the findings on the employment creation in refurbishing and e-waste recycling business in Ghana:

²⁵ Total labour force in Ghana was estimated to be about 10.33 million in 2009 (CIA 2010)

²⁶ Urban population in Ghana represents about 48% of the total Ghanaian population, which lies at about 24 million (CIA 2010)

Table 5 Number of people employed and dependent on refurbishing and e-waste recycling in Ghana
(Source: Own calculations)

	Refurbishers	Collectors	Recyclers	Total
Employed in Accra	10,000–15,000	4,500–6,000		14,500–21,000
Employed in Ghana	14,000–24,000	6,300–9,600		20,300–33,600
Dependent on re- furbishing and e- waste recycling in Accra	60,000–90,000	27,000–36,000		87,000–126,000
Dependent on re- furbishing and e- waste recycling in Ghana	84,000–144,000	37,800–57,600		121,800–201,600

3.4.3 Contribution to national economy

Estimates based on the socioeconomic data collected in Accra reveal that in Ghana between 10,000 and 13,000 metric tons of e-waste is treated annually. Although there is no quantitative information on the role e-waste recycling materials play in the development of other sectors, it is still possible to estimate the contribution of total refurbishing and e-waste recycling sector to the national economy in Ghana on the basis of average salaries (see section on Remuneration) and the number of workers (see section on employment creation). The table below shows how the value creation by refurbishing and e-waste recycling sector in Ghana can be calculated.

Table 6 E-Waste's contribution to the Ghanaian national economy (Source: Own calculations)

	Refurbishers	Collectors	Recyclers	Total
Remuneration per month (in US\$)	190–250	70–140	175–285	435–675
Remuneration per year (in US\$)	2,280–3,000	840–1,680	2,100–3,420	5,220–8,100
Number of people employed in refurbishing and e-waste recycling sector in Ghana	14,000–24,000	6,300–9,600		20,300–33,600
Contribution to national economy per year (in US\$)	Remuneration per year (in US\$) multiplied by the number of people employed in refurbishing and e-waste recycling sector in Ghana			105,966,000– 268,128,000

Thus, it is estimated that the value creation by the refurbishing and e-waste recycling sector in Ghana could range between US\$ 105 and 268 million annually. Due to the informal nature of the refurbishing and e-waste recycling sector in Ghana, this contribution is not reflected in

the national GDP²⁷. Assuming that the contribution of this sector is added to the national GDP, it will make about 0.29% to 0.55% of the total GDP of Ghana.

3.4.4 Contribution to national budget

Due to the sector's widespread informality and the dominance of small-scale enterprises, many businesses in refurbishing and e-waste recycling sector are not included in the national taxation system. During the primary data collection, none of the interviewees from the group of collectors and recyclers reported of paying taxes to the government. Nevertheless, few formally operating enterprises, mostly refurbishing and repair businesses, are subject to taxation, such as Internal Revenue Service (IRS), Value Added Tax (VAT) and local revenue to the Accra Metropolitan Authority (AMA).

3.4.5 Impacts on conflicts

It is well known that a rapid increase in demand for raw materials used in electronic products gives rise to conflicts over resources worldwide (Manhart 2009; Manhart 2007). The e-waste recycling industry could actually play an important role in reducing such conflict risks, i.e. the higher the recovery rate of metals in e-waste, the lower the pressure on primary mining sites, such as those of gold, palladium and tantalum.

Furthermore, as already mentioned under section "Indigenous rights", there is some local pressure on the government to remove the Agbogbloshie community as a result of protests and demands from the members of the Ga community. Ga community considers Agbogbloshie as their traditional living area, and are not willing to accept their displacement to overcrowded conditions elsewhere in Accra. Consequently, there is genuine fear among politicians that delays in the planned eviction of the current Agbogbloshie community could spark off ethnic tensions (Du Plessis 2005).

Secondly, delayed implementation of the Korle Lagoon Ecological Restoration Project (KLERP), including the removal of Agbogbloshie, has been putting the government under pressure from funding agencies for the KLERP project, namely the Arab Bank for Economic Development in Africa, the Agence France de Développement, and others). Therefore, there have been several attempts, albeit unsuccessful, from the local government to evict the present communities of Agbogbloshie, leading to political tensions and protests by the residents and human rights groups in Ghana.

4 Analysis of present and best applicable recycling technologies

The results of the socio-economic assessment show that the currently practiced form of e-waste collection and recycling in Ghana has both, severe negative impacts such as health

²⁷ GDP of Ghana – 36.57 billion (estimated in 2009) (CIA 2010)

impacts on workers and neighbouring communities, as well as positive impacts in terms of employment creation and significant contribution to the national economy. This differentiated picture of the current situation leads to the conclusion that a ban on the current practices – without offering alternative employment opportunities – would have severe unintended side-effects, especially on the people and communities that today make their living from this waste stream. Furthermore, some of the root causes of the problem, the domestic generation of e-waste in Ghana and the demand for affordable second-hand equipment, would remain unchanged by a ban of certain recycling practices²⁸. A ban would therefore not entirely solve the problem but would only lead to a shift thereof.

For this reason, this section looks into feasible ways to upgrade the currently practiced e-waste recycling in Ghana with a view to reduce environmental impacts, to maintain and generate employment opportunities and to improve social standards within this sector.

4.1 Recycling of desktop computers²⁹

4.1.1 Relevance for Ghana

Desktop computers are widely used in West African countries. In contrast to notebooks, desktops are affordable at moderate prices. Used desktops are sold to prices ranging from US\$ 60 per device for a basic set-up to US\$ 100 for a desktop with a more modern processor like Pentium IV.

The end-of-life management of desktop computers is of high importance as they contain a broad variety of hazardous substances such as heavy metals and persistent organic pollutant. The EU-Directive 2002/95 on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) led to a reduction of the use of cadmium, lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) in devices produced for the European market after June 2006. Nevertheless, electronic equipment like computers still contains various other hazardous substances that have not been addressed by this legislation (Groß et al. 2008).

With regard to the desktop computers sold on the Ghanaian second-hand markets, it is estimated that the majority of devices was produced before 1st July 2006, i.e. the implementation date of the RoHS-Directive. This assumption is supported by material tests on used computers in Nigeria – a country with similar structured second hand markets – in

²⁸ Another root cause, the import of obsolete equipments not suitable for reuse, must be considered additionally. In contrast to the other root-causes, there is a broad consensus that such imports require strong regulative action such as a complete ban of all e-waste imports.

²⁹ In this study, the term “desktop computer” is used for the computing device only and does not include monitors or peripherals such as computer mouse or keyboards.

2009 that revealed that lead levels in printed wiring boards exceed the European RoHS threshold by the factor of 90 (Osibanjo 2009).

Hazardous substances are mostly contained in printed wiring boards, electronic components and plastic parts. Generally, all plastics used in computers contain flame retardants, with mostly hazardous characteristics. Additionally, the PVC of cables is of concern when heated or burned (formation of dioxins).

Other electronic devices like DVD-players, hi-fi- and stereo-systems and set-top-boxes feature similar material compositions so that solutions for desktop PCs can also be applied to these product groups.

4.1.2 Presently applied recycling technologies

The presently applied recycling technologies in Ghana include the following steps:

- Collection by informal waste collectors;
- Removal of functioning components for re-use (cables, memories, drives...);
- Manual dismantling to extract steel, aluminium and copper parts and open incineration of cables and components to recover copper;
- Disposal of residues.

Additionally, fire is frequently used to reduce the waste volumes on uncontrolled dump sites. Furthermore, it is noteworthy that capacitors are collected separately and discarded uncontrolled. This is done because capacitors can explode when incinerated.

The recovered metals are either sold to traders or directly to refinery units. While there are several aluminium remelters and electric steel plants in the port city Tema, there is no copper refinery in Ghana. Therefore, copper is exported to foreign copper plants, mostly to the Middle East via Dubai and to Asia via Hong Kong.

Occasionally, foreign traders come and buy printed wiring boards, which are then shipped to Asian destinations.



Photo 7 Burning activities at Agbogbloshie Metal Scrap Yard, Accra (Source: Öko-Institut 2009)

4.1.3 Best applicable recycling technologies

For an environmentally sound recycling, waste desktop computers, at first, have to be collected from private households and businesses. Subsequently, they have to be dismantled and sorted according to their main fractions (pre-processing). Thereby, emphasis must be laid on the management of all fractions contained in desktop computers, as a pure focus on individual fractions would lead to an uncontrolled accumulation of hazardous material.

The output fractions then have to be passed on to refineries that are able to recover the materials at high quality and at high environmental standards (end-processing). Fractions that are not suitable for material recovery have to be managed in an environmentally sound manner.

Collection

The collection of obsolete electronics is a key aspect of an e-waste recycling system, as the collection mechanism determines the amount of e-waste channelled towards recycling and the amount being lost in storage and/or uncontrolled disposal.

Generally, there are various possible ways of organising collection systems: In many European countries, e-waste collection is organised in municipal collection points, where consumers are obliged to hand in their obsolete devices. Although the collection points can ensure a proper sorting of devices, these systems are strongly dependent on public awareness as the efforts for the transport to the collection point has to be made by the consumers themselves. This generally results into imperfect collection rates because many consumers opt to avoid the effort of travelling to the collection point and seek more convenient ways of getting rid of their old devices. In the case of small and medium sized e-waste, this circumstance leads to quite low collection rates in Europe (Darby & Obara 2004; Huisman et al. 2007).

In contrast, in many developing countries and emerging economies, e-waste collection is organised in an informal door-to-door collection system, where collectors pay money to pick-up used and obsolete electronic devices together with other, mostly metals containing waste fractions. In Accra, collectors pay around US\$ 1.0 to 2.5 (1.40 to 3.50 GHS) for one obsolete desktop computer. In terms of collection rates, these collection systems are estimated to be far more efficient than centralised bring-in systems. Nevertheless, such door-to-door collection systems can only be operated at low wages for the waste pickers or with subsidies from public or private sources.

Pre-processing

There is a wide range of different pre-processing technologies available, from shredding, crushing and various types of mechanical sorting to purely manual operations. Generally, these different types of pre-processing technologies can be classified into two major groups:

- mechanical shredding and sorting,
- manual dismantling and sorting.

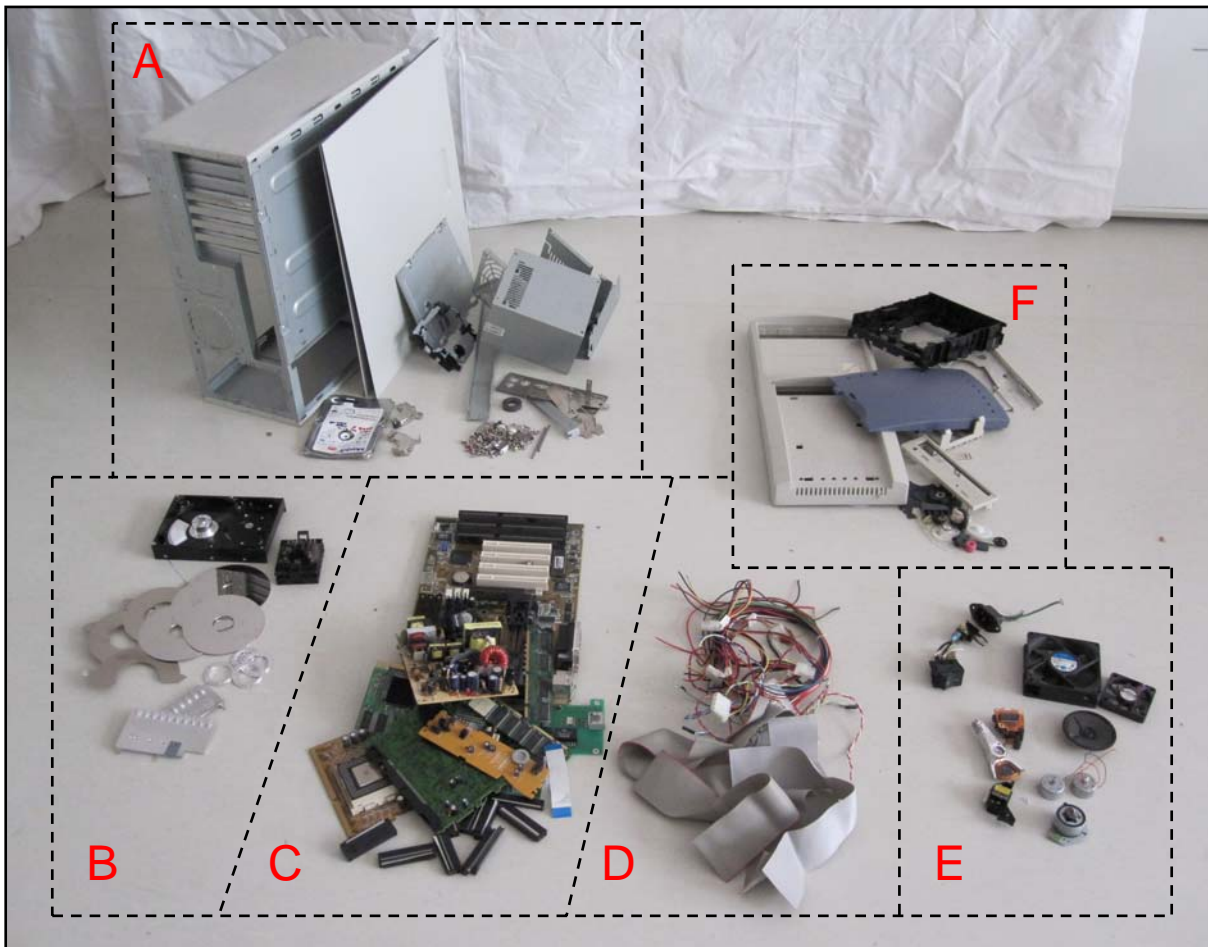
There is a broad consensus that manual pre-processing has clear benefits in terms of material recovery if compared to mechanical pre-processing. One key problem of mechanical pre-processing is the fact that shredding and sorting does not achieve perfectly pure output fractions: As many e-waste fractions consist of various closely interwoven materials, mechanical shredding cannot liberate each material out of all its interconnections. In the subsequent sorting processes this will inevitably lead to losses of certain materials in other output streams. Furthermore, each sorting technique relies on some distinct physical properties (e.g. density, magnetism, electric conductivity), which are in reality co-influenced by other factors such as particle size and cohesion to other particles. So even with fully liberated input material, some particles will end up in the wrong output stream. Although

these problems could partly be reduced by technical improvements, resource losses are to some extent inevitable with these technologies (Hagelüken 2006). For precious metals, these losses are estimated at roughly 20%–58% (Hagelüken et al. 2005, Salhofer & Spitzbart 2009). Manual pre-processing technologies achieve output fractions of much higher quality so that losses in the subsequent refinery processes can be minimised. Nevertheless, the depth of the manual dismantling is still of high importance for the total system yield: Salhofer & Spitzbart (2009) proved that deep dismantling of desktop computers down to the level of subcomponents such as the printed wiring boards of hard drives, power supplies, floppy and CD/DVD-drives achieves highest recovery rates.

Generally, it strongly depends on the socio-economic conditions whether manual pre-treatment is economically preferable to mechanical pre-treatment. Salhofer & Spitzbart (2009) conclude that – despite lower material recovery rates – mechanical pre-treatment operations are mostly economically preferable to manual pre-treatment under Central European conditions. Nevertheless, in regions with lower wage levels like China, it was proved that even in times of lower resource prices as of 2003, manual pre-treatment is clearly preferable from both, an environmental and economic perspective (Gmünder 2007). Additionally, manual dismantling and sorting operations require only very low investment costs for simple tools and can be carried out by unskilled personnel. Compared to mechanical pre-treatment, manual pre-treatment is significantly more labour intensive.

The output of the manual pre-processing operations encompasses the following fractions:

- steel scrap (cases, structural elements, screws...),
- aluminium scrap (heat sinks, structural components of drives, hard disks...),
- high grade precious metals fraction (PWBs, contacts),
- copper cables,
- low grade copper fraction (motors, drive readers, speakers ...),
- plastics (cases, structural elements...).



A = Steel scrap B = Aluminium scrap C = High grade precious metals fraction
D = Copper cables E = Low grade copper fraction F = Plastic fraction

Photo 8 Manually dismantled and sorted desktop PC (Source: Öko-Institut 2010)

Nevertheless, even with deep manual dismantling, some copper and precious metals containing components like cables, small motors and reading/writing devices of drives need further pre-treatment. Although even these steps could be carried out manually, the economic output might not justify the high labour intensity. Therefore, this residual fraction could be passed on to mechanical pre-treatment facilities. Thereby it is of particular importance to identify alternative local treatment options for cables in order to eliminate the common practice of cable burning (see photo 7). Generally, copper cables can either be stripped manually using knives and bench vices (to fix the cables), or automatically using a cable shredder or cable granulator. Both options have distinct strengths and weaknesses, which can be summarised as follows:

- Manual cable stripping is only suitable for thick cables. With thin cables, it is quite difficult to liberate all copper strings from the insulation.

- Manual stripping is very labour intensive. As scrap yard workers at Agbogbloshie are now used to the practice of burning, it might be difficult to convince them to deploy significantly more labour for comparable copper outputs.
- Automatic shredder and sorting machinery is capital intensive and requires investments costs in a range of US\$ 25,000 to 100,000 – depending on size and capacity of the installation³⁰. Additionally, the machinery needs electricity (usually 400V at 50Hz) as power demands are in a range of 3 to 100kW.
- Unsound operation of shredders can lead to dust emissions and dioxin formation. This is especially the case, when the machinery runs hot.
- Both, manual cable stripping and mechanical shredding lead to copper losses into the plastic fraction. This might require a subsequent sorting of the plastic fraction in a saltwater-bath (plastic floats, while copper sinks).

Taking these issues into account, it can be concluded that despite some disadvantages, mechanical cable shredders should be deployed to provide alternatives to the common burning practice.

End-processing

The output fractions of the manual pre-treatment are passed on to end-processing operations. Ideally, such end-processing operations are able to combine efficient material recovery with high environmental standards.

The steel scrap is processed in electric arc furnaces that produce secondary steel products. There are currently five electric arc furnaces operating in the port city of Tema.

The aluminium scrap is passed on to aluminium remelters that produce cast alloys from aluminium scrap. There are several aluminium remelters in the region of Accra and Tema.

The high grade precious metals fraction can be sold to two major types of end-processing enterprises: Pyrometallurgical refineries and hydrometallurgical refineries. Thereby it has to be noted that pyrometallurgical refineries focus on a wide range of metals, while hydrometallurgical refineries exclusively target precious metals.

In terms of recovery rates of precious metals, pyrometallurgical refineries are preferable to hydrometallurgical refineries as the melting process affects all input materials, while the hydrometallurgical treatment only affects the surface layer of the feed material. Although the PWBs can be grinded to particle sizes that allow quite comprehensive treatment, these physical size reduction processes are also likely to generate precious metals losses. Additionally, interactions of chemicals also reduce the effectiveness of metal recovery (Schluep et al. 2009). From an environmental perspective, there is an ongoing debate on the sustainability of hydrometallurgical refineries: While some authors argue that they provide a

³⁰ Cable shredders / granulators are usually available with capacities ranging from 50kg/hr to 1000kg/hr.

low cost solution for emerging economies (Cui & Zhang 2008), others stress the fact that hydrometallurgical processes have not yet published comprehensive flow sheets and that the type of processes – using strong acids or caustic solutions – are associated with considerable risks for human and environmental health. A comprehensive overview on the critical issues of hydrometallurgical refineries is presented in Schlupe et al. 2009.

The copper from cables and the low grade copper fraction can be sold to secondary copper refineries. The low grade copper fraction is especially attractive for secondary copper-steel smelters with a focus on processing mixed steel-copper scrap. Generally, it is beneficial to remove larger plastic parts to increase the fraction's purity.

The plastic fraction is mostly composed of ABS and Polycarbonates used for cases and structural components. Furthermore, thermosets like epoxy resin are used for PWBs and in coatings and housings of electronic components, switches and motors. PVC is used for cable insulations. All these plastic types have in common that they are permeated with flame retardants. Especially those plastic parts that – during the use-phase of the products – are exposed to heat usually feature high concentrations of flame retardants.

Generally, the thermosets from PWBs and electronic components are strongly interlinked with the copper and precious metals fraction and are used as fuel and reducing agent in the metal refining process. The thermoplastics (ABS and Polycarbonates) can theoretically be recycled into new products. Nevertheless, the contamination with flame retardants significantly reduces the options for secondary applications as with the established recycling methods these constituents will be part of the new products. For consumer safety reasons, this is unacceptable for many applications. Furthermore, the secondary use of these materials will only postpone the end-of-life problem associated with hazardous flame retardants and might lead to the problem of cross-contamination. Especially if used in a wide range of applications, the subsequent situation of broadly dispersed flame retardants might be even worse than today, where plastics with flame retardants can easily be identified on the basis of their original function. Even secondary applications in new electric and electronic devices largely prove infeasible, as the majority of new products are designed to comply with the European RoHS-Directive strongly limiting the use of the flame retardants PBB and PBDE. Although ongoing research projects aim to identify ways to depolymerise and clean thermoplastics from e-waste (Arends 2009), these techniques are not yet applicable on an industrial scale. Therefore, one option for the management of plastics from waste computers is energy recovery in power plants or cement kilns with sophisticated off-gas treatment. Alternatively, plastics could also be disposed off in engineered landfills for hazardous waste. As there are currently no cement kilns, waste incinerators and engineered landfills located in Ghana, the implementation of these solutions requires structural investments.

Interim conclusion

In the Ghanaian context, the best applicable recycling technologies for desktop computers can be sketched as follows:

- House-to-house collection of e-waste;
- Manual pre-treatment, including deep dismantling up to the level of parts of sub-components;
- Mechanical shredding or granulation of cables;
- Further manual pre-treatment of low grade copper fraction to reduce plastic content;
- Refinery of steel and aluminium fraction in domestic plants;
- Refinery of high grade precious metals fraction in pyrometallurgical refineries abroad;
- Refinery of copper and low-grade copper fraction in copper or steel-copper refineries abroad;
- Controlled incineration / energy recovery or landfilling of remaining plastic fraction.

4.1.4 Economic incentives for environmentally sound recycling

The intrinsic material value of desktop computers is mainly based on two major groups of metals: The bulk metals copper, steel and aluminium and the precious metals represented by gold, silver and palladium (see Table 7).

Table 7 Material content, intrinsic and net values of an average desktop computer (without monitor and peripherals) at 2007 resource prices) (Sources: Gmünder 2007; USGS 2009a, b; CSR 2009)

	Amount contained in a desktop computer [g/unit]	Average material price 2007 [US\$/t]	Intrinsic material value 2007 [US\$/unit]	Estimated recovery rates with presently applied technology	Estimated recovery rates with best applicable technology	Net material value with presently applied technology [US\$/unit]	Net material value with best applicable technology [US\$/unit]
Steel	6,737.501	253*	1.70	95%	95%	1.62	1.62
Plastics	1,579.545	310**	0.49	0%	0%	0	0
Aluminium	550.212	2,700	1.49	88%	78%	1.31	1.16
Copper	413.225	7,231	2.99	85%	98%	2.54	2.93
Zinc	25.940	3,400	0.09	0%***	0%***	0	0
Tin	19.573	19,800	0.39	0%	0%***	0	0
Antimony	18.577	5,660	0.11	0%	0%***	0	0
Nickel	12.700	37,200	0.47	0%***	0%***	0	0
Lead	6.585	2,730	0.02	0%	0%***	0	0
Silver	1.702	550,000	0.94	0%	87%	0	0.81
Gold	0.260	22,400,000	5.82	30%	93%	1.75	5.42
Palladium	0.120	11,488,748	1.38	0%	91%	0	1.25
Chromium	0.015	2,010	0.00	0%***	0%***	0	0
Ceramics & others	371.909	-	-	-	-	-	-
Sum	9737.860		15.88			7.22	13.19

* Prices for iron & steel scrap ** Prices for mixed plastic *** Partly indirectly recovered together with other metals

With the described best applicable recycling technologies (see section 4.1.3), up to 95% of steel and 88% of aluminium can be recovered. These figures are based on the assumption that thorough manual disassembling and sorting is able to recover 95% of the steel and 98% of aluminium of massive components like cases, frames and large heat-sinks. For printed wiring boards it is estimated that only large aluminium parts (heat sinks) are removed prior to refining. Unlike in the presently applied recycling, smaller aluminium parts are not removed in order not to damage IC-components and to prevent precious metals losses. As aluminium is not recovered in the subsequent copper and precious metals refining processes, this leads to approximately 10% aluminium-losses³¹ (calculated with data from Gmünder 2007 and Salhofer & Spitzbart 2009).

Copper is used in cables, coils, contacts, motors (motors of fans, CD/DVD-drives and hard drives) and printed wiring boards. It is assumed that manual pre-treatment operations can

³¹ The motherboard and the printed wiring boards of the drives and the power supply contain 40% of the aluminium in a desktop computer. It is estimated that removable heat sinks make up 50% of this aluminium fraction.

recover 100% of the copper contained in cables. The copper contained in printed wiring boards and contacts is treated in high-tech refineries which can recover 100% of the copper contained in the input material. Copper contained in components like motors can only partly be recovered as these components need to undergo mechanical pre-processing which inevitably leads to some material losses. Therefore, the net-recovery rate is estimated to be 98%.

Palladium, gold and silver are concentrated in printed wiring boards (motherboards, graphic cards, sound cards, modem cards and the boards of drives and power supply...) and contacts. Currently, these fractions are partly shipped to Asian destinations, presumably for hydrometallurgical recovery of gold. The efficiency of such gold recovery operations has been estimated to be between 6% and 30% (Keller 2006). Alternatively, these fractions can be fed into high-tech metallurgical refineries with recovery rates of 92% to 96%. Minor concentrations of precious metals can also be found in motors, hard discs and reading/writing devices. Nevertheless, these fractions need further mechanical pre-treatment and sorting prior to refining. In these operations, losses of precious metals occur. Therefore, the total recovery rate for silver, gold and palladium are somehow lower at 87%, 93% and 91% respectively (calculated with data from Salhofer & Spitzbart 2009 and Umicore 2009).

The recovery rates of zinc, tin, antimony, nickel, lead and chromium are difficult to determine. While tin and lead are mainly used in solders, antimony is used as a flame retardant in plastic parts. Zinc, nickel and chromium are used in alloys. The tin, antimony, nickel and lead contained in PWBs are recovered as by-products in integrated smelters. The zinc, nickel and chromium of alloys are recovered together with the scrap aluminium, steel and copper to generate new products.

The comparison between the net material values of the presently applied recycling technologies and the best applicable recycling technologies shows that revenue from recycling of one desktop computer could be increased from US\$ 7.22 to 13.19. Nevertheless, these figures have only indicative character, as resource prices are in constant change. Furthermore, it has to be kept in mind that these revenues cannot be made by one individual recycler, but can only be achieved by a complex and well organised recycling chain that includes precious metals refineries in Europe, Canada or Japan. Additionally, the figures represent only the potential sales revenues, not taking into account labour and transport costs, logistics, taxes and investment costs.

4.1.5 Environmental benefits

The proposed recycling system for desktop computers has significant advantages over the status quo in terms of management of hazardous substances. First of all, the precious metals containing fraction (PWBs and contacts) would be treated in state-of-the-art smelters located in Europe, Japan or Canada, the proposed recycling system would lead to an export flow of a waste fraction featuring high concentrations of heavy metals and organic pollutants

(Hagelüken 2006). Furthermore, these smelters are all equipped with sophisticated off-gas treatment, so that also the net emissions of hazardous substances like dioxins would be significantly minimised.

Secondly, the proposed system would provide significant potentials in terms of resource efficiency. As indicated in chapter 4.1.4, the recovery rates of gold would raise from 30% to 93% and for silver and palladium to 87% and 91% respectively. Although these increases in efficiency would have slightly negative impacts on the recovery rate for aluminium, the net efficiency would be clearly beneficial. From an environmental perspective, this is of high importance, as the secondary production of metals has significantly less environmental impacts than primary production (see table 8). With optimised recovery rates of silver, gold and palladium, a total of 5.23 kg CO_{2eq} could be saved per desktop computer if compared to primary mining of the same amount of metals.

Table 8 Energy demand and greenhouse gas emissions of primary and secondary metal production for one desktop computer (without monitor and peripherals) (Source: Calculated with data from Ecolnvent 2009 and Gmünder 2007)

	Fe (steel)	Al	Cu	Ag	Au	Pd
Primary production						
CED [MJ/kg]	29.63	187.26	54.49	1,641.56	298,128.96	166,642.02
GWP [kg CO _{2eq} /kg]	2.04	10.20	2.81	112.14	17,879.75	9,284.30
Secondary production						
CED [MJ/kg]	8.33	22.79	0.84*	119.31*	6,964.43*	3,647.91*
GWP [kg CO _{2eq} /kg]	0.40	1.32	0.10*	14.31*	835.40*	437.57*
Amount per device [g]						
	6,737.50	550.21	413.23	1.70	0.26	0.12
Recovery potential [%]						
	95	78	98	87	93	91
Environmental impacts of secondary production from the recycling outputs of 1 desktop computer						
CED [MJ]	53.34	9.78	0.34	0.18	1.68	0.40
GWP [kg CO _{2eq}]	2.54	0.57	0.04	0.02	0.20	0.05
Environmental impacts of primary production of the same amount of materials as from recycling of 1 desktop computer						
CED [MJ]	189.62	80.37	22.06	2.43	72.09	18.20
GWP [kg CO _{2eq}]	13.07	4.38	1.14	0.17	4.32	1.01
Saving potential through recycling of 1 desktop computer [absolute]						
CED [MJ]	136.28	70.59	21.73	2.25	70.40	17.80
GWP [kg CO _{2eq}]	10.53	3.81	1.10	0.14	4.12	0.97
Saving potential through recycling of 1 desktop computer [%]						
CED [%]	72	88	98	93	98	98
GWP [%]	81	87	96	87	95	95

CED = Cumulative Energy Demand, GWP = Global Warming Potential

* Secondary production from electronic and electric scrap recycling in pyrometallurgical refinery.

Thirdly, the mechanical pre-processing of cables would significantly reduce the emissions of persistent organic pollutants as it would offer an alternative to the current practice of cable burning.

4.1.6 Health and safety issues and labour intensity

Although desktop computers contain quite a variety of hazardous substances, none of these substances is present as liquid or gas. This circumstance makes the proper transport and pre-processing of waste desktop computers quite manageable compared to other e-waste types. The most important aspect to avoid human and environmental contamination is to minimise the generation of dust and to avoid unsound management practices such as uncontrolled melting or burning operations. As the proposed recycling system primarily foresees manual collection and pre-treatment and no melting or burning operations, the health and safety risks are manageable. Varin & Roinat (2008) provide a good overview on the recommended health and safety measures of manual pre-processing operations. The following paragraph is therefore entirely copied from this work:

“Even though manual dismantling operations generate few contaminants likely to be absorbed by the respiratory route, dismantling technicians are advised to wear masks. Contamination happens mostly indirectly, by ingestion of contaminants present on hands and cloths. Employees must therefore respect the following minimum safety instructions:

- *Wear protection suits, or regularly clean these suits by washing separately;*
- *Do not eat, drink or smoke in the workshops;*
- *Wash hands before meals and snacks;*
- *Avoid nail biting and brush one’s nails regularly;*
- *Vacuum the premises to avoid dust accumulation.”*

In addition, the mechanical pre-processing of cables requires special health and safety training to avoid injuries during operation. Furthermore, workers have to be trained to keep the machinery in an operation mode that prevents the emission of dust and the formation of dioxins.

In terms of labour intensity, the proposed manual pre-processing is quite labour intensive. The time requirements for workers have been measured by Gmünder (2007) in China and by Salhofer & Spitzbart (2009) in Germany. While in the Chinese case, 83 working hours were needed to disassemble 1 t of desktop computers,³² the German case required 7.5 hours for the same amount. Thereby it has to be noted that in the Chinese case, workers used simple tools and only partly electric screwdrivers and were engaged in very deep dismantling

³² 1 t of desktop computers roughly equals 100 devices.

operations. In contrast, the German workers were equipped with electric tools throughout the operations and carried out a much less detailed dismantling. Additionally, the German test used a batch of identical computers, so that workers did not face the challenge of different computer constructions, set-ups and screw types. For the Ghanaian case, it is therefore more realistic to calculate with around 80 working hours per tonne or 50 minutes per device.

For the pre-processing of cables, only few workers are required to run and maintain the machinery. Depending on the size and capacity of the shredders, it is estimated that 5 to 30 workers are required to run and maintain the machinery to take care of all cables in the Accra region. Thereby, labour intensity will be higher, if semi-automated sorting technologies such as saltwater baths are deployed.

4.1.7 Interim conclusion and possible business models

The comparison of the presently applied recycling technologies and the best applicable technologies reveals that there are significant untapped economic, environmental and social improvement potentials. These potentials can be realised by manual pre-treatment in Ghana and exporting the precious metals bearing fractions to one of the few pyrometallurgical refineries in Europe, Canada or Japan. As the value of the recoverable precious metals sums up to US\$ 7.48 per desktop computer at 2007 resource prices, under usual conditions these values can compensate the costs for manual pre-treatment, logistics, transport and refinery.

From the type of operations needed in Ghana, it is obvious that this business is largely independent from investments into machinery parks or infrastructure. The investment into comprehensive pre-processing machinery would, on the contrary, reduce the economic potentials of this approach and would also have negative impacts on employment creation.

Furthermore, the manual pre-processing operations can be run by medium and low-skilled workers. Therefore, the business is suitable to be implemented within the current informal recycling sector in Ghana.

Nevertheless, the question whether the described potentials can be entirely realised in practice largely depends on the type of the business model and the links between Ghanaian recyclers and large scale refineries. Therefore, different business models need to be analysed on the basis of their specific strengths and weaknesses. In order to be feasible, each business model must – as minimum requirements – fulfil the following functions:

- Within the business model, it is necessary to establish and maintain contractual links between pre-processing operations in Ghana and pyrometallurgical refineries in Europe, Canada or Japan. Furthermore, the business model needs at least one actor that is capable of handling administrative issues related to the transboundary shipment of e-waste. In the current situation, where e-waste recycling is dominated by unregistered informal enterprises, many local players might face severe difficulties in this regard.

- As most of the workers engaged in e-waste recycling in Ghana have no financial reserves, the business model needs to ensure steady and reliable cash flow to the involved workforce. Thereby, the time lag between pre-processing of e-waste in Ghana and the final marketing of the resources is critical. It is estimated that the times for the collection of sufficient export volumes, the transport, the sampling and the refinery will sum up to several months. For a workforce that depends on rapid cash flow, this time span represents a severe obstacle.
- Besides paving the road for the export of certain e-waste fractions, the business model must also ensure a steady know-how transfer to the recycling sector in Ghana. This know-how must cover issues, such as information on values contained in the various e-waste fractions, the best treatment options for hazardous components, information on changing material compositions and measures to further increase the economic, environmental and social benefit of the recycling operations.

Based on these minimum requirements there are two major types of possible business models:

Model 1: Indirect co-operation with one or more intermediaries

An easy way to overcome the limitations of the informal sector would be a business model that installs one or more intermediaries between the informal e-waste sector and the pyrometallurgical refineries. Such intermediaries must be capable of fulfilling the requirements listed above. Thereby, they would act as formal joint between the informal e-waste sector in Ghana and the refining companies. Nevertheless, such a business model might be critical in situations where intermediaries have a monopoly position and can control the local prices for pre-processed e-waste. From other resource markets, it is known that many intermediaries dealing with informal sector activities use such monopoly positions to bring down prices and to maximise their own profit margins (Wagner et al. 2007). Furthermore, intermediaries are not necessarily interested in comprehensive know-how transfer as they are themselves not involved in e-waste pre-processing and therefore do not have to fear negative health and safety impacts themselves. Additionally, intermediaries might be tempted to focus on high grade precious metals fractions only, while neglecting other hazardous fractions with lower intrinsic value. Although such 'cherry-picking' might be suitable in the initial phase to get the business model started, it has long-term side-effects as low value and hazardous e-waste would further accumulate in Ghana.

Model 2: Direct co-operation between small-scale recyclers and refineries

By establishing a direct link between small-scale recyclers in Ghana and pyrometallurgical refineries, some of the drawbacks and risks associated with intermediaries could be avoided. Ideally, such direct links would be established on the basis of a cooperative or community-based approach within the Ghanaian e-waste sector. Such an approach should be capable of managing the formal and administrative business requirements, as well as caring for a fair

distribution of incomes. Nevertheless, such an approach would obviously require significant efforts to bring the e-waste sector in the position to link with international recycling partners. Amongst others, micro-finance schemes might be needed to enable basic types of upfront investments and to secure the cash flow to e-waste workers. Furthermore, the know-how transfer needs to be established and organised in a way that ensures benefits to all members of the cooperative.

4.2 Recycling of CRT-devices

4.2.1 Relevance for Ghana

Cathode ray tubes (CRTs) are used in old TVs and computer monitors. These CRT-devices are still widely used in Ghana as they provide a cheap alternative to the modern flat screen panels. In contrast to Europe, there is still a large market for used CRTs and repair services for CRTs. Used CRT-TVs are sold for prices ranging from US\$ 35 per device for a small device to above US\$ 100 for large TVs. Used computer monitors sell for US\$ 18 to US\$ 35.

The end-of-life management of CRTs is of high importance as they contain a broad variety of hazardous substances such as heavy metals and persistent organic pollutants. In addition to the flame retardants and heavy metals contained in printed wiring boards and plastics, the glass tube itself is of concern because of its high lead-oxide content. Barium-oxide and strontium-oxide are of additional concern. Although under usual conditions, the substances are bound in the glass matrix, crushing and weathering of CRT-class leads to long-term emissions into soil and groundwater (ICER 2003), a process that is likely to be accelerated under tropical conditions such as in Ghana. Additionally, the internal phosphorous coating of the front contains cadmium and other pollutants (ICER 2003). This coating is partly released as dust when CRTs are broken (see chapter 3).

4.2.2 Presently applied recycling technologies

The presently applied recycling technologies in Ghana include the following steps:

- Collection by informal waste collectors,
- Removal of functioning components for re-use (cables, power supplies ...),
- Removal of deflection and focusing coils (mostly by breaking off the neck glass),
- Manual dismantling to extract steel, aluminium and copper parts and open incineration of cables and components to recover copper,
- Uncontrolled crushing and disposal of CRT glass and residues.

The recovered metals are sold along with metal fraction of other e-waste recycling activities (see chapter 4.1.2).

4.2.3 Best applicable recycling technologies

Collection

The CRTs have to be collected and transported to pre-treatment operations. During transport and handling, it is important that the tubes are not broken to prevent emissions of the internal phosphorous coating and to ensure that all CRT-glass is channelled into the proper end-of-life management.

Pre-processing

Pre-processing starts with the manual dismantling into the main components and fractions, namely steel, aluminium, printed wiring boards, cables, low grade copper fraction, plastic fraction and glass-tube. Apart from the tube, all fractions can be managed along with the fractions obtained from the recycling of desktop computers (see chapter 4.1.3). Nevertheless, it has to be considered that TV and monitor boards have significantly lower precious metals contents so that the costs for shipment and refinery might not be justified from an economic perspective. In order to overcome this problem, the boards can further be pre-treated by taking off steel and aluminium parts and possibly also some of the larger electronic parts like capacitors. This will relatively 'upgrade' the copper and precious metals content of the boards. Furthermore, the obtained steel and aluminium – which would be lost in the copper and precious metals refining process – can be sold to secondary steel and aluminium smelters.

The appropriate pre-treatment of the glass tube depends on the envisaged type of end-processing. In case the glass is recycled into new CRTs, the front glass needs to be separated from the funnel glass. This step is important as the compositions of the two types of glasses are significantly different: While the funnel glass contains an average of 13% of lead-oxide, the front glass is widely free from lead but contains 8% barium-oxide and 4% strontium-oxide (ICER 2003). The separation of the different glass types can either be done by semi-automated cutting or by automated shredder and sorting technologies. Generally, semi-automated technologies require lower investment costs and are more labour intensive (Zumbuehl 2006). Nevertheless, it is difficult to treat large quantities of CRTs with these technologies.

If the glass is passed on to lead or copper smelters, the front and funnel glasses do not necessarily have to be separated. Nevertheless, most smelters prefer sorted CRT-glass as this enables a better adjustment of the right feed-mix.

If the glass is used in the construction sector, no separation of front and funnel glass is needed. Nevertheless, high lead-oxide content might lead to long-term lead emissions which could be prevented by reducing the share of funnel glass.

In any case, the pressure in the tube needs to be equalised prior to further treatment to avoid implosion. This means that a small hole has to be punched into the tube to release the

vacuum in a controlled manner. This hole can easily be made where the anode connection is attached to the tube. Then, the glass (separated or not) needs to be crushed and compacted. During this process, the internal phosphorous coating is partly emitted as dust, containing cadmium and other pollutants. Therefore, all crushing operations have to be carried out under a fume hood with an attached filter system to collect the dust.

The output of the pre-processing operations encompasses the following fractions:

- steel scrap (cases, structural elements, screws...),
- aluminium scrap (heat sinks, structural components of drives, hard disks...),
- precious metals fraction (PWBs),
- copper fraction (focusing and deflection coils, cables...),
- low grade copper fraction (electronic parts, speakers ...),
- plastics (cases, structural elements...),
- mixed or sorted CRT-glass,
- phosphorous dust.

End-processing

All fractions except from CRT-glass and the phosphorous dust can be managed together with the fractions of the desktop computer recycling (see chapter 4.1.3).

For CRT-glass, there are various management options: The most preferable from an economic and environmental perspective is the recycling into new CRT-glass (glass-to-glass recycling) (Kang & Schoenung 2005). Nevertheless, CRT-production has almost come to an end, as today the market for TVs and computer monitors is dominated by LCD and plasma technology. There is only one remaining CRT-production in India that accepts secondary CRT-glass of high quality. Nevertheless, this facility has an established supplier structure so that it is unlikely that new players will be able to enter this market.

The second established management option is the use of CRT-glass in lead or copper smelters (glass-to-lead recycling). Thereby, the glass is used as flux agent and substitute for silica sand. The lead from the glass can partly be recovered in the process. The silica is moving into the slag phase. There are only few smelters that are technically designed in a way that they can process CRT-glass. In 2003, there were three smelters accepting limited amounts of CRT-glass in Europe. At that time, these capacities were not sufficient to manage the end-of-life CRTs of Great Britain (ICER 2003). In the USA, there are only two smelters processing CRT-glass (Kang & Schoenung 2005).

Another recycling option is mixing CRT cullet with concrete or asphalt to be used in the construction sector. This management option could be attractive for Ghana as it could build upon existing industry structures. Nevertheless, this option still faces the problem of possible

cross-contamination so that it has to be proved from case to case that the hazardous substances incorporated in the building materials constitute no risk to human health and the environment.

Other recycling options encompass the production of foam glass, ceramic bodies and insulating glass fibre. Nevertheless, these applications are still in an experimental stage and have not yet resulted into a management option for end-of-life CRT-glass (Andreola et al. 2007).

A commonly used end-of-life management option for CRT-glass is the transfer to hazardous waste disposals.

The phosphorous dust also needs to be disposed as hazardous waste.

Interim conclusion

In the Ghanaian context, the best applicable recycling technologies for CRTs can be sketched as follows:

- House-to-house collection of CRTs and careful handling in order not to damage the tubes;
- Manual dismantling into main fractions;
- Manual upgrading of printed wiring boards;
- Compaction of tubes under a fume hood with attached filter system;
- Refinery of steel and aluminium fraction in domestic plants;
- Refinery of precious metals fraction in pyrometallurgical refineries abroad;
- Refinery of copper fraction in copper refineries abroad;
- Controlled incineration / energy recovery or controlled disposal of remaining plastic fraction
- Careful use of glass culets in construction sector or disposal as hazardous waste;
- Disposal of phosphorous dust as hazardous waste.

4.2.4 Economic incentives for environmentally sound recycling

The main value carrier of CRTs is copper, which makes up more than 60% of the total intrinsic value (see Table 9). The majority of this copper is used for the focusing and deflection coils (see Photo 9). Therefore, these components are highly attractive for recyclers.



Photo 9 Focusing and deflecting coils of manually dismantled CRTs (Source: Öko-Institut 2010)

Table 9 Material content, intrinsic and net values of an average CRT-TV at 2007 resource prices (Sources: Eugster et al. 2007; Hagelücken 2006; USGS 2009a, b; CSR 2009)

	Amount contained in a CRT-TV [g/unit]	Average material price 2007 [US\$/t]	Intrinsic material value 2007 [US\$/unit]	Estimated recovery rates with presently applied technology	Estimated recovery rates with best applicable technology	Net material value with presently applied technology [US\$/unit]	Net material value with best applicable technology [US\$/unit]
Glass	17,043	0	0	0%	0%	0	0
Plastics	6,880	310**	2.13	0%	0%	0	0
Steel	2,990	253	0.76	95%	95%	0.72	0.72
Copper	900	7,231	6.51	85%	98%	5.53	6.38
Aluminium	598	2,700	1.61	88%	88%	1.42	1.42
Tin	31	19,800	0.62	0%	0%***	0	0
Lead	22*	2,730	0.06	0%	0%***	0	0
Nickel	6.7	37,200	0.25	0%***	0%***	0	0

	Amount contained in a CRT-TV [g/unit]	Average material price 2007 [US\$/t]	Intrinsic material value 2007 [US\$/unit]	Estimated recovery rates with presently applied technology	Estimated recovery rates with best applicable technology	Net material value with presently applied technology [US\$/unit]	Net material value with best applicable technology [US\$/unit]
Silver	0.62	550,000	0.34	0%	87%	0	0.30
Gold	0.04	22,400,000	0.85	0%	93%	0	0.79
Palladium	0.02	11,488,748	0.26	0%	91%	0	0.23
Ceramics & others	1,434	-	-	-	-	-	-
Sum	29,900		13.38			7.67	9.84

* Only lead contained in the TV-board ** Prices for mixed plastic *** Partly indirectly recovered together with other metals

With thorough manual disassembling and sorting it is estimated that 95% of steel, 88% of aluminium and 85% of copper can be recovered. The copper recovery rate can be increased by refining the printed wiring boards in integrated smelters.

Palladium, gold and silver are concentrated in printed wiring boards and contacts. It is estimated that the recovery rate is equivalent to those of desktop computers (see section 4.1.4).

The recovery rates of tin, lead and nickel are difficult to determine. While tin and lead are mainly used in solders, nickel is used in alloys. The tin and lead contained in PWBs are recovered as by-products in integrated smelters. The nickel of alloys is recovered together with the scrap aluminium, steel and copper to generate new products.

The comparison between the net material values of the presently applied recycling technologies and the best applicable recycling technologies shows that revenue from recycling of one CRT-TV could be increased from US\$ 7.67 to 9.84. Nevertheless, this calculation does not include the costs for environmentally sound management of the CRT-glass and the disposal of the internal phosphorous coating. As sketched in chapter 4.2.3, there is an oversupply of CRT-glass, leading to a situation where providers of the glass have to pay for its environmentally sound end-processing. In the first half of 2010, the costs for co-processing in copper-smelters ranged between US\$ 120 and 200 per ton (Wouters 2010). Assuming an average price of US\$ 160 per ton, this would imply costs of US\$ 2.73 per device. This means that the revenues from environmentally sound recycling of CRTs are lower than the revenues from the currently practiced recycling (declining from US\$ 7.67 to 7.11) – not even taking into account the costs for sound disposal of the phosphorous dust and possible costs for the controlled incineration of plastics. Even if the other recommended management option for CRT-glass is chosen, i.e. transfer to dumpsites for hazardous waste – this would imply costs, which would partly neutralise the revenues from other fractions.

As already indicated in chapter 4.1.4, all revenue and cost figures are indicative only. It has to be kept in mind that the turnovers cannot be made by one individual recycler, but can only be achieved by a complex and well organised recycling chain that includes local Ghanaian recyclers as well as transport agencies and refineries located in other countries. Additionally, the figures represent only the potential sales revenues, not taking into account labour and transport costs, logistics, taxes and investment costs.

4.2.5 Environmental benefits

The proposed recycling of CRTs would especially lead to a better management of hazardous substances. While pollutants contained in the printed wiring boards would be managed in smelters abroad, the organic pollutants in the plastic fraction would be widely destroyed in controlled incineration in cement kilns.

Controlled compaction of CRTs and the sound management of the trapped dust would reduce emission of cadmium.

The lead, barium and strontium contained in the CRT-glass would also be better managed as the material would be better protected from weathering and mechanical impacts; pre-supposing proper disposal and/or proper use in construction material.

4.2.6 Health and safety issues and labour intensity

The main health and safety risk during CRT-recycling is the exposure to cadmium containing dust emissions during breaking, cutting and compacting operations of CRT-glass. In addition, risks of injury from imploding tubes, glass splinters and the handling of heavy devices have to be considered.

In addition to the health and safety measure described in chapter 4.1.6, workers while dismantling and compacting CRTs should wear respiration masks to avoid the inhalation of dust, safety glasses to protect the eyes from splinters and further protective clothing like robust gloves, protective shoes and aprons. Breaking, cutting and compaction operations of CRT-glass should, in any case, only be carried out under fume hoods with an airflow that fully evacuates the dust emission from the tubes. The outgoing airflow needs to be filtered to avoid heavy metal emissions to the neighbourhood.

Although no precise data on the labour intensity of manual dismantling and compaction of CRTs is available, it is estimated that per unit labour requirements are lower than with desktop computers, as both, CRT-TVs and CRT-monitors feature less sub-components to be dismantled. It is assumed that the manual dismantling and compaction steps require around 30 minutes per device.

4.2.7 Interim conclusion and possible business models

The comparison of the presently applied recycling technologies with the best applicable technologies reveals that there are considerable environmental improvement potentials, especially in terms of managing the hazardous fractions like CRT-glass, the internal phosphorous coating and plastics. Nevertheless, the environmentally sound management of these fractions is costly and will at least partly compensate the revenues from the net material value of CRT-devices. Compared to the presently applied CRT-recycling, the environmentally sound treatment path would yield clearly less revenues. Therefore, it cannot be expected that profit-orientated enterprises will engage in environmentally sound CRT-recycling without additional financing systems or other safeguard mechanisms that ensure a proper handling of all fractions of CRT-products. In the current situation, it is much more profitable for both, formal and informal businesses to conduct 'cherry picking' by focusing on the valuable fractions only and discarding the rest.

Therefore, any business models to implement environmentally sound CRT-recycling can only compete against such cherry-picking recyclers, if laws and regulations clearly outline the recyclers' full responsibility for all waste fractions. Additionally, finance mechanisms should be installed that compensate for the management of these deficit fractions. One possibility could be to apply extended producer responsibility (EPR) in Ghana by charging a fee for any electric or electronic device imported to Ghana. This fee could then be used to finance environmentally sound end-of-life management of critical e-waste fractions.

Additionally, sound CRT-recycling could be supported by identifying suitable management options for critical fractions. This could include:

- the identification and development of disposal sites for hazardous wastes;
- minimum quotas for co-incineration of hazardous wastes in cement kilns;
- further exploring the feasibility of using CRT-glass in the construction sector.

4.3 Recycling of refrigerators and freezers

4.3.1 Relevance for Ghana

Refrigerators are commonly used in W-African countries, both, in private households and in shops and bars.

The end-of-life management of refrigerators and freezers is of considerable environmental importance as most devices manufactured before 1993 contain refrigerants and foam blowing agents with a high ozone depleting and greenhouse gas potential. Although the refrigerants and foaming agents are not directly hazardous to human health, the potential greenhouse gas emissions from crude recycling or untreated disposal are very high (see Table 10). As the average life-span of cooling and freezing appliances is between 14 and 17 years in Europe (Rüdenauer & Gensch 2007), the majority of devices reaching end-of-life in

Europe is still based on the CFCs R11 and R12 or the HFC R134a. In fact, only 15% of the cooling and freezing equipment reaching end-of-life in Germany in 2008 were already based on hydrocarbons with much lower greenhouse gas potential (Holst 2008). For West African countries – which meet their demand for household appliances to a large extent by the import of devices diverged from the waste collection in European countries³³ – it can be estimated that a large amount of imported second-hand refrigerators contains CFCs or HFC. As these devices are mostly refurbished and used for several further years, the end-of-life stream of cooling and freezing equipment in W-Africa will continue to feature very high shares of CFC and HFC-appliances in the near future.

Table 10 Type and amount of refrigerant and foaming agent according to year of manufacture (Sources: Gabel et al. 1998; Rüdener & Gensch 2007; IPCC 2007)

Date of manufacturing	before 1988	1988–1993	1993–1997	from 1994
Refrigerant	R12	R12	R134a	R600a
Amount in „small“ appliance	140 g	105 g	95 g	36 g
Amount in „large“ appliance	332 g	249 g	226 g	85 g
Foaming agent (PUR-foam)	R11	R11	R134a	Cyclopentane
Amount in „small“ appliance	358 g	247 g	165 g	194 g
Amount in „large“ appliance	851 g	587 g	392 g	460 g
GHG-potential of refrigerant & foaming agent [CO ₂ -equ]				
CO ₂ -equ in „small“ appliance	3.23 t	2.32 t	0.37 t	0.0022 t
CO ₂ -equ in „large“ appliance	7.66 t	5.50 t	0.88 t	0.0053 t

³³ In contrast to many other used electric and electronic equipment imported to W-Africa, shipments of refrigerators from North-America are negligible, as the refrigerators designed for the North-American 110V grid cannot be used in W-African countries.

Table 11 Specification of the chemicals used as refrigerant and foaming agent (*Sources: IPCC 2007; LANUV 2009*)

	Technical name	Chemical formula	Ozone Depleting Potential [R11 = 1]	Global Warming Potential _{100a} [CO ₂ = 1]	Flammable
CFC	R11	CCl ₃ F	1.00	4,750	no
	R12	CCl ₂ F ₂	1.00	10,900	no
HFC	R134a	CH ₂ FCF ₃	0.00	1,430	no
Hydrocarbon	R600a (Isobutene)	CH(CH ₃) ₃	0.00	3	yes
	Cyclopentane	c-C ₅ H ₁₀	0.00	11	yes

In addition to ozone depleting substances (ODS) and other greenhouse gases, especially older refrigerators and freezers contain other fractions of concern, which include mercury switches and PCB-containing capacitors. Flame retardants are not a major problem of cooling and freezing equipment and might only be an issue of the plastic fraction that is closely interlinked with electric components. Nevertheless, the PVC of cable isolations is of concern when heated or burned. Furthermore, the cooling circuits of absorption refrigerators³⁴ contain ammonia and chrome-VI, so that end-of-life management of these devices is also critical.

Additionally, many end-of-life air conditioners also use CFCs as cooling agent. Therefore, solutions for refrigerators and freezers can also be applied to air conditioners.

4.3.2 Presently applied recycling technologies

The presently applied recycling in Ghana starts with the collection of the devices. Refrigerators and freezers are mostly collected by informally operating individuals and groups that pick up the obsolete devices from households and shops. Usually, these people pay between US\$ 1.50 and US\$ 5.00 US\$ (2.10–7.00 GHS) for one device. The refrigerators and freezers are then transported by handcart to a scrap metal yard, where the refrigerators are manually dismantled. Thereby, the focus is on the recovery of steel, copper and aluminium. Other fractions, including CFCs, plastics and foam, do not undergo any particular management. Although, the corpses are sometimes reused as boxes, the plastics and the foam are routinely discarded or burned.

³⁴ Absorption refrigerators represent only a small percentage of the total cooling and freezing appliance market. Absorption refrigerators are usually only used in hotel rooms and mobile homes.



Photo 10 Corpuses of refrigerators after manual extraction of steel, copper and aluminium (Source: Öko-Institut 2010)

It is noteworthy that there is currently a UNDP project operating in Ghana that aims to promote energy-efficient and CFC-free refrigerating appliances in Ghana³⁵. The project is embedded in an overarching strategy by various government bodies for the refrigeration sector in Ghana. It is funded by the Global Environment Facility (GEF) and the Multilateral Fund for the Implementation of the Montreal Protocol (MLF). Amongst others, the project will set up a refrigerator collection and recycling system to recover and destroy CFCs. If successful, this project might significantly restructure the current refrigerator recycling in Ghana. In general, the envisaged refrigerator recycling will be based on the following strategies:

- Old functioning and non-functioning refrigerators will be collected by offering a coupon for each old refrigerator. The coupon can be redeemed for cash in a participatory bank.

³⁵ The project “Promoting of Appliance Energy Efficiency and Transformation of the Refrigerating Appliance Market in Ghana” is executed by the Ghanaian Energy Commission and is implemented between April 2010 and March 2013.

- In seven recycling centres distributed over the country, the refrigerators will be dismantled and CFCs from the cooling circuits will be extracted. Foams will be manually recovered and stored in air sealed plastic bags or painted with air proof lacquer coat in order to prevent vaporisation of CFCs. To date, no final solution for the foams has been identified.
- The CFCs from the cooling circuits will be shipped abroad for destruction or, alternatively, will be destroyed in plasma ovens to be imported from Japan. In case the second destruction option is chosen, the destruction process will be carried out in one location in Accra.

4.3.3 Best applicable recycling technologies

For an environmentally sound recycling of CFCs or HFC containing refrigerators and freezers, the capture and destruction of refrigerants and foaming agents is indispensable. Furthermore, other fractions of concern (mercury switches, PCB-containing capacitors, ammonia, chrome-VI and cable-insulations) have to be taken care of.

Collection

The refrigerators have to be collected and transported to dedicated recycling facilities. During transport, it is important that the cooling circuit is not damaged to prevent CFC or HFC emissions.

Step 1 of CFC-recovery

Step 1 of the recycling process encompasses the recovery of the refrigerants in the cooling circuits of refrigerators and freezers. This is carried out in a semi-automated process: First, the main electricity cable and unhitched parts in the interior (e.g. glass shelves, gridirons, plastic boxes) are removed manually. The valuable fractions of these removed parts (glass, polystyrene, iron, aluminium) are passed on for further processing. Additionally, the capacitors³⁶ and – if present – the mercury switches are removed. These parts have to undergo special hazardous waste disposal.

For the subsequent degassing of the cooling circuit, the refrigerator has to be lifted and tilted. Then, the cooling circuit is tapped at its lowest point using a special device that minimises potential leakage (photo 11). The cooling circuit is then evacuated using negative pressure. The oil-refrigerant mixture is collected in a tank and treated thermally to separate the refrigerants.

³⁶ Although not all capacitors contain PCB, the differentiation is difficult in many cases. Therefore, it is recommended to treat all capacitors uniformly as hazardous waste.

Step 1 is followed by a manual extraction of the compressor and possibly the cooling grid at the backside of the device. The corpses are passed on to step 2 of the CFC-recovery process.



Photo 11 Step 1 of CFC recovery from refrigerators (Source: Öko-Institut 2010)

Step 2 of CFC-recovery

In step 2 of the refrigerator recycling process, the CFCs in the isolation-foam (PUR-foam) of the devices are recovered. Generally, there are two major ways to carry out step 2:

The first option is based on manual extraction of the foams, using scraping and cutting tools to separate the PUR-material from the casing material. The foam is then passed on to a treatment facility that is able to incinerate the foam at temperature regimes that destroy the

CFCs. According to the TEAP Task Force on Destruction Technologies, cement kilns or municipal solid waste incinerators are suitable for this operation (UNEP 2007). Nevertheless, some experts argue that cement kilns and waste incinerators might be unable to guarantee complete CFC destruction, as the temperature regime within these plants is often not uniform and frequently falls below the necessary 850°C (Becker 2010). Furthermore, during manual extraction of the PUR-foam, a significant share of the CFCs is already emitted in the breaking and cutting operations. According to a study carried out by Schüler & Dehoust (2010), these losses amount to 16 to 30% of the CFCs contained in the foam. Therefore, this kind of foam treatment can only be regarded as a low standard and low cost alternative³⁷.

The second option is based on fully automated treatment that is completely situated in a sealed environment. In this set-up, the devices are passed through an airlock into a shredder and shearing system. To separate the foam material, the shredder output is passed through an air stream separator. Subsequently, the foam is milled to free the CFC. Furthermore, the resulting foam powder is heated to evaporate the CFC contained in the PUR-material itself. The CFC-containing process air is then passed through a charcoal absorber. After the absorber's capacity is exhausted, the charcoal is heated to liberate the CFC and to regenerate the absorber. The CFC is collected in a tank and shipped to further treatment using thermal or plasma destruction technologies.

The complete recycling process, including the automated option for step 2 of the CFC-recovery process, yields the following output fractions:

- Steel fraction
- Aluminium fraction
- Copper fraction
- Polystyrene fraction
- PUR-powder
- Mixed plastics fraction
- Glass fraction
- Refrigerants and foaming agents (mix of CFCs, HFCs, cyclopentane)
- Oil
- Hazardous fraction (PCB-capacitors, mercury switches...)

End-processing

While the metal fractions can be organised together with the metal outputs from other e-waste fractions (see chapter 4.1.3), the polystyrene of refrigerators and freezers is of quite

³⁷ Another possible obstacle for incineration in cement kilns is the fact that the chlorine content negatively influences cement quality, which might provoke the opposition of cement producers.

good quality and free from additives like flame retardants. Therefore, it can be passed on to the plastics recycling industry. In Ghana, there are several recyclers of thermoplastics, which could make use of this material.

The PUR-powder can be used as oil binding agent without further processing. The mixed plastic fraction is composed of various types of plastics including thermosets and elastomers, which cannot be recycled. Therefore, this fraction should be incinerated in cement kilns or waste incinerators along with other problematic waste fractions (see chapter 4.1.3).

The glass fraction can be fed into local glass recycling industries.

The recovered CFCs should be treated in certified facilities using one of the destruction technologies approved by the UNEP Task Force on Destruction Technologies. Such facilities are currently installed in Europe, Australia, Brazil, Canada and Japan (UNEP 2007). Alternatively, small scale plasma ovens could be imported and installed in Ghana. The oil from the cooling circuit can be passed on to oil fired industrial plants to be used as fuel.

The hazardous fraction needs to undergo specific treatment and disposal. For PCB-containing capacitors, the infrastructure and management pathways to be established under the UNDP-project "PCB Management in Ghana, from Capacity Building to Elimination" could be used³⁸.

Interim conclusion

In the Ghanaian context, the best applicable recycling technologies for refrigerators and freezers can be sketched as follows:

- House-to-house collection of refrigerators and freezers and careful transport to prevent leakages of the cooling circuit
- Semi-automated extraction of CFCs from cooling circuits
- Automated recovery of CFCs from foams
- Refinery of steel and aluminium fraction in domestic plants
- Export of copper fraction
- Local recycling of polystyrene
- Marketing of PUR-powder as oil binding agent
- Export and destruction of CFCs in certified facilities
- Controlled incineration / energy recovery of oil and remaining plastic fraction

³⁸ The project is funded by the Global Environment Facility (GEF) to build up collection, dismantling and storage places of PCB-containing transformers and capacitors in Accra and Tema. Although the project mainly addresses PCB in industrial applications (electricity generation and distribution), co-processing of capacitors from refrigerators and freezers should be feasible. The project is implemented between 2009 and 2014 and managed by a Steering Committee chaired by the Ministry of Environment, Science and Technology. EPA Ghana is providing the project secretariat (UNDP 2009b).

- Controlled management of hazardous fraction

The question, whether a step 2 recycling unit is feasible in the short or medium-term remains open. In contrast to step 1, an automated step 2 CFC recovery operation requires significant investments into machinery (several million US\$) and generates only very little employment. On the other side, manual extraction of foams and its direct incineration in cement kilns is associated with many other problems. As a possible middle-way, it might be elaborated to search for a third option based on the manual extraction of foams, combined with an automated recovery of CFCs. Nevertheless, there is no machinery readily available for such an alternative treatment path.

Generally, refrigerator recycling should, in any case, be linked to sound quality assurance mechanisms. Such mechanisms could be provided by independent organisations such as RAL Quality Assurance for the Demanufacturing of Refrigeration Equipment or other technical inspection associations.

4.3.4 Economic incentives for environmentally sound recycling

The intrinsic material value of refrigerators is mainly based on the bulk metals copper, steel and aluminium (see table 12). Depending on the applied treatment technology, between 96% and 99% of the ferrous and between 80% and 92% of the non-ferrous metals can be recovered in the recycling processes (Dehoust & Schüller 2007). It is assumed that a partial deployment of manual dismantling and sorting processes will lead to the above average recovery rates of 99% for ferrous metals and 92% for non-ferrous metals.

The value of the various types of plastics is difficult to determine: While the polystyrene of refrigerators – which on average makes up 45.2% of the total plastic content – is of high purity and may achieve a considerable market price after recovery, the pulverised PUR-foam (approximately 4 kg per device) can be used as oil binding agent. The other plastic fractions are of low quality and may only be suitable for energy recovery (Dehoust & Schüller 2007). Generally, there is no globally interlinked market for secondary plastics, so that prices in one region cannot be easily transferred to another region. Therefore, the material values for plastics listed in table 12 are indicative figures only. The table indicates that – from a resource perspective – the best applicable technology is preferable for its better utilisation of plastics, namely polystyrene and PUR. The recovery rates for metals are equal to those of the presently applied technologies.

Additional incentives for an environmentally sound recycling of refrigerators and freezers result from the high greenhouse gas potentials of the refrigerants and foaming agents: A sound recovery and destruction of these gases, as carried out with the best applicable technologies would generate significant greenhouse gas emission reductions that – under certain preconditions – can be certified and sold under one of the existing emission reduction certification schemes, namely the Clean Development Mechanism (CDM), the Climate Action

Reserve (CAR) or the Voluntary Carbon Standard (VCS). In order to facilitate an overview on these trading schemes, some important characteristics are presented for each of them:

- CDM only allows emission trading credits from gases that are covered by the Kyoto Protocol. As CFCs are listed under the Montreal Protocol and not under the Kyoto Protocol, R134a is the only relevant gas contained in refrigerators and freezers that could be used to generate CDM credits. Therefore, CDM seems only attractive for projects that have a strong additional focus on emission reductions through increased energy efficiency (replacement of old refrigerators by more efficient devices)³⁹.
- CAR additionally included the destruction of CFCs into possible emission reduction measures in early 2010 (CAR 2010). It gives credits for CFCs from cooling circuits but not for CFCs from foams. Therefore, projects can only generate CAR-credits from step 1 CFC-recovery and destruction. Moreover, R 22, a refrigerant frequently used in air-conditioners, is not eligible under CAR. The recovered CFCs have to be shipped to the USA for destruction. ODS recovery and destruction projects are temporally limited to 12 months. Long term CFC-recovery and destruction efforts might have the possibility to be accepted as several 12-month projects.
- In parallel to CAR, also VCS included ODS destruction into its scheme in early 2010 (VCS 2010). In contrast to CAR, VCS does not provide a methodology laying out the basis for CFC recovery and destruction projects. Methodologies have to be developed according to the framework provided by VCS (VCS 2008). As there have already been several ODS destruction methodologies submitted to the Voluntary Carbon Standard Association, it can be assumed that applicable project methodologies will soon be available. In contrast to CAR, both, refrigerants and foaming agents are eligible. The targets for recovery and destruction efficiency are 85% of the addressed CFCs. This means that especially CFC-recovery from foams will have to meet high standards.

³⁹ Every CDM activity involving refrigerator replacement needs to ensure sound measures for CFC-recovery and destruction from cooling circuits and foams – disregarding the fact that the emission reductions from CFC-destruction are not eligible under CDM.

Table 12 Material content, intrinsic and net values of an average refrigerator at 2007 resource prices
(Sources: DTI 2006; USGS 2009; CSR 2009)

	Amount contained in a refrigerator [kg/unit]	Average material price 2007 [US\$/t]	Intrinsic material value 2007 [US\$/unit]	Estimated recovery rates with presently applied technology	Estimated recovery rates with best applicable technology	Net material value with presently applied technology [US\$/unit]	Net material value with best applicable technology [US\$/unit]
Steel	20	253*	5.06	99%	99%	5.01	5.01
Plastics	16	310**	4.96	0%	65%	0	3.22
Copper	1.6	7,231	11.57	92%	92%	10.64	10.64
Aluminium	1.2	2,700	3.24	92%	92%	2.98	2.98
Glass	0.4	31	0.01	92%	92%	0.01	0.01
Others	0.8	-	-	-	-	-	-
Sum	40		24.84			18.65	21.87

* Prices for iron and steel scrap ** Prices for mixed plastics

Despite this lack of applicable market data for VCS and CAR emission reductions from ODS-recovery and destruction, these schemes will undoubtedly support the economic basis for refrigerator recycling in developing countries. Generally, it can be assumed that market prices of several US\$ per ton of prevented CO₂_{equ}-emission could be achieved. Thereby, the pricing will also depend on the quality of the recycling project, including its verification mechanism and its compliance with international standards.

4.3.5 Environmental benefits

In contrast to the currently applied recycling of refrigerators and freezers, the best applicable technologies would reduce the emissions of CFCs from the cooling circuit and – if step 2 of the recovery operation is implemented – also those from the foams. With an implementation of up-to-date technology of step 1 and 2 recovery units, a minimum of 90% of CFCs contained in refrigerators and freezers can be recovered. Depending on the size and type of refrigerator, this would lead to a proper management of 2–7 t CO₂_{equ} per device.

Additionally, sound recycling operations would improve the management of hazardous components such as PCB-containing capacitors or mercury switches.

Positive aspects also result from the utilisation of the plastic fraction, namely the recycling of polystyrene and the PUR-material. Regarding the PUR-powder from step 2 recovery of CFCs, it is noteworthy that this output can be used as oil binding agent or agent to thicken liquid hazardous wastes.

4.3.6 Health and safety issues and labour intensity

The health and safety risks during the recycling operations of refrigerators and freezers can be divided into three categories:

- health risks from hazardous substances contained in the devices;
- safety risks from handling heavy devices;
- safety risks from the operation of recycling machinery.

Hazardous substances are present in mercury switches of old box-type freezers, in PCB-containing capacitors as well as in the ammonia and chrome-VI contained in the cooling circuits of absorption refrigerators. The CFCs and HFCs contained in foams and cooling circuits are not directly hazardous to human health. Therefore, leakages and spills of these substances are undesirable from an environmental perspective, but do not affect workplace health and safety.

Although the components containing pollutants can be easily identified by trained workers, the substances of concern are all present in a liquid form so that proper management guidelines and handling procedures must be in place. Furthermore, workers have to be trained how to recognise and treat the relevant components.

Additionally, risks associated with handling and lifting of heavy devices with partly more than 40kg have to be taken into account.

In terms of safety risks from the operation of recycling machinery, special emphasis on fire risks is needed: As non-CFC and non-HFC refrigerators contain flammable hydrocarbons, a co-processing with CFC and HFC refrigerators leads to an accumulation of flammable gases within the recovery machinery of recycling step 1 and 2⁴⁰. Especially during CFC-recovery step 2, these hydrocarbons can cause fires or explosions within the recovery unit. Therefore, sophisticated precaution measures have to be installed. Amongst others, automated CFC-recovery units must be operated in a nitrogen atmosphere.

Operation of one unit of the step 1 CFC-recovery process requires about six workers and one engineer. With this workforce, roughly 30 devices can be treated per hour and 60,000 per year. The automated step 2 CFC-recovery operation requires one or two additional engineers to achieve the same treatment capacity. Additional manual labour can be deployed to further dismantle and sort some of the recycling outputs such as the evacuated compressors.

4.3.7 Interim conclusion and possible business models

The comparison of the presently applied recycling technologies and the best applicable technologies reveals that there are significant untapped environmental and possibly economic improvement potentials. These potentials can be realised by the recovery of CFCs and HFCs from cooling circuits and foams and the destruction of these Ozone Depleting Substances in dedicated facilities. Additionally, the sound management of hazardous components and a better utilisation of the plastic fraction add to the benefits of sound refrigerator

⁴⁰ The co-processing of hydrocarbon devices is to some extent unavoidable, as some devices are insufficiently marked or may have lost their marks during their life-time.

recycling. Economic benefits can be tapped, if the CFC and HFC-recovery and destruction are marketed within one of the existing emission trading schemes. The Carbon Action Reserve (CAR) and the Voluntary Carbon Standard (VCS) just established the frameworks for such financing.

From a social perspective, the recovery and destruction of CFCs and HFCs do not create significant employment. Nevertheless, the establishment of a sound refrigerator recycling infrastructure can help to form a nucleus of a future recycling industry and therefore play a more indirect role in creating decent employment in an environmentally sound industry.

From the type of operations needed in Ghana, machinery to recover CFCs and HFCs are required. The investment costs into one step 1 recovery unit with a capacity of 30 devices per hour are approximately US\$ 280,000 (€ 200,000). As step 1 of the recovery can be conducted in an open area (by deploying a recovery unit built into a container), a building is not necessarily needed. Nevertheless, paved floor, electricity and sufficient space to store and handle obsolete refrigerators are required. The investment costs for an integrated operation of step 1 and 2 amount to US\$ 6.3 million (€ 4.5 million).

Considering these investment costs and the tasks to tackle issues around export of CFCs, certification and compliance, the informal e-waste sector might not be in the position to manage this kind of recycling alone. Nevertheless, businesses should closely interlink with the current e-waste recycling structures to avoid competition in acquiring obsolete refrigerators. The informal e-waste sector could in particular be engaged in collection of obsolete refrigerators, transport to the recycling facility and the manual recycling steps.

As there is already a UNDP-project on refrigerator recycling in Ghana, further efforts to improve this sector should be closely interlinked with this project.

Regarding the implementation and possible follow-up-activities of the UNDP-project “Promoting of Appliance Energy Efficiency and Transformation of the Refrigerating Appliance Market in Ghana”, the following recommendations can be given:

- The collection system should consider the informal sector. Although many collection systems in industrialised countries are based on bring-in systems directly addressing private households and businesses, the situation is different in low income countries like Ghana. In Ghana, refrigerators are mostly collected by informal waste collectors going from house-to-house using hand carts and paying cash money for metals containing wastes. For households and businesses, this is a convenient way to get rid of obsolete equipment as transport and handling are completely taken over by the informal sector. Furthermore, the system offers employment for many unskilled people. In contrast, the envisaged collection system is personalised and requires that the person to hand in an old refrigerator is the same person that is granted a coupon that can be redeemed for cash in a participatory bank. Non-functioning refrigerators will have to be handed over to representatives of *Zoomlion*, a waste management company operating in Ghana. Old functioning refrigerators will have to be handed over

to a representative of *NARWOA*, the National Refrigerator and Air-Conditioning Workshop Owners Association (UNDP 2009c). Generally, it seems unlikely that consumers and businesses can be convinced to routinely deliver their waste refrigerators to collection points themselves. It seems more likely that the informal sector will continue collecting refrigerators and will offer the service of delivering old and obsolete refrigerators to the dedicated collection points and to handle all administrative procedures. As this does not have any implications for the success of the project – and additionally helps to secure many low-skilled jobs in waste collection – such informal sector engagement should be tolerated. In particular, it should be tolerated that individuals with no registered residential address and telephone number can acquire coupons by handing in old and obsolete refrigerators. Additionally, no limit for the number of devices and coupons per person should be applied.

- In order to prove an effective instrument to channel refrigerators away from the currently practiced informal recycling, the coupons given out for each obsolete refrigerator must have a monetary value that is clearly above the refrigerator's net material value (see Table 12). If this is not the case, refrigerators will continue to be recycled with the presently applied technologies.
- In order to ensure sound transport and handling of refrigerators, full-value coupons should only be granted for devices that arrive with intact cooling circuit. For devices with leakages or missing components, only coupons with a minor monetary value should be distributed. Nevertheless, these devices should not be rejected as they mostly still contain significant amounts of CFCs in the foams.
- The dismantling of refrigerators should – as far as possible – make use of manual labour and avoid the use of mechanical shredding and sorting machinery. Although machinery is necessary for step 1 and step 2 CFC-recovery, all other process steps, including the dismantling and sorting of the metal and plastic fractions should be carried out manually. This measure is aimed to maximise the project's job creation.
- In order to ensure the project's acceptance in the current refurbishing and recycling industries and to provide a nucleus for improved recycling businesses, it is recommended to install the CFC-recovery and destruction facilities within or close to the current refurbishing or recycling clusters. Drawing from the findings of the socio-economic survey and considering experiences from other economies, these clusters do have significant development potentials, which could be stimulated by such pilot projects. In particular, the CFC-recovery and destruction facilities should make use of the present labour force to create decent employment and to upgrade skills and knowledge. Furthermore, some non-hazardous process steps like the dismantling of steel and copper parts could be outsourced to existing informal recycling enterprises.
- Final solutions for foams and hazardous refrigerator components (e.g. mercury switches, PCB-capacitors) must be identified and implemented. This could also include

collection and clean-up mechanisms of foams stored as boxes or littering on informal dumpsites. As explained in chapter 4.3.3, these solutions could encompass controlled incinerations in cement kilns or alternatively, a fully automated CFC-recovery.

- For CFC-destruction, volumes and treatment capacities must be aligned. As it is planned to set up seven recycling centres for step 1 CFC recovery, this would create a treatment capacity of more than 1500 refrigerators per day⁴¹. The subsequent CFC-yield would sum up to 300 kg per day, which is clearly overstressing the capacity of two plasma oven for R12 destruction (each 10 kg per day). Considering this disproportion, it should be considered to either calculate with a higher destruction capacity or to deploy a mobile CFC-recovery unit.

4.4 Possible risks and unintended side-effects

The business potentials from improved e-waste recycling as analysed in the chapters 4.1 to 4.3 can have multiple positive impacts on the environment and the Ghanaian society. Nevertheless, the business models might also face obstacles and entrepreneurial risks. Additionally, the implementation of the business models might also cause unintended side-effects that can in turn have negative impacts on the environment and the Ghanaian economy. Although it is virtually impossible to make an exhaustive assessment of these risks, the following collection of issues highlights some foreseeable topics that need to be considered in the future.

4.4.1 Dangers of negligence of non-valuable fractions

The business opportunities identified in the chapters 4.1 to 4.3 are based on revenues generated from e-waste fractions with positive net values. These fractions encompass PWBs and IC-contacts (precious metals), copper, steel and aluminium. With regard to refrigerators, revenues could possibly be generated from CFCs via voluntary emission reduction schemes. Nevertheless, other fractions like plastics or composite materials will not find major markets within or outside Ghana. Environmentally sound end-of-life management is therefore – at best – cost neutral. With regard to hazardous components like CRT-glass, PCB-containing capacitors, mercury switches or ammonia, sound end-of-life management is costly and dependent on additional financing mechanisms.

This issue needs careful consideration in any follow-up activity. If the business models described above are implemented without additional safeguard mechanisms to care for these deficit fractions, it is very likely that they will be disposed of in the cheapest possible manner, disregarding possible risks to human and environmental health. One possible finance

⁴¹ Usually, one step 1 unit has a capacity of 30 refrigerators per hour. Assuming eight hours operation per day in seven facilities, this would result in a total step 1 capacity of 1680 devices per day.

mechanism is to use a share of the revenues generated from the valuable fractions to manage the deficit fractions.

4.4.2 Problems related to the changing composition of e-waste

The analysis conducted in chapters 4.1 to 4.3 is based on the current e-waste situation in Ghana, where desktop computers, CRT-monitors and CFC-refrigerators are amongst the most dominant types of e-wastes. Nevertheless, this situation will gradually change within the next decade: As many of these devices are replaced by notebooks, LCD-screens and CFC-free refrigerators, the e-waste stream will also change its composition once these products reach their end-of-life. Although this will have many positive effects as new devices often contain less hazardous substances as old ones⁴², changes in product design and technologies will inevitably create the need to adapt the end-of-life management. One important example is LCD-technology: Although LCD-monitors have not yet reached the Ghanaian waste stream in significant quantities, this is just a matter of time as use and demand – either as stand-alone devices or as parts of notebooks or other appliances – are increasing. LCD-screens carry significant amounts of valuable metals, but at the same time are quite difficult to dismantle without causing mercury emissions from broken backlights. To date, the optimal recycling of these devices is still unresolved (Huisman et al. 2007).

Therefore, efforts for environmentally sound e-waste recycling need to consider these changes in material compositions and regularly update their know-how and recycling practices.

4.4.3 Variations of resource prices

Recycling approaches that are financed by the net material value of e-waste, need to consider possible variations of resource prices. As illustrated by Figure 3, the net material value provided by precious metals and copper is characterised by long- and short-term variations with a major peak around mid-2008 and followed by a downturn caused by the economic crises. Although the values almost reached this level by the end of 2009, the future developments are uncertain. Currently, many experts predict that prices for most commodities will remain at high levels for the next years (World Bank 2010). These predictions generally assume a stable development of the world economy. With regard to e-waste recycling, the high importance of the gold price is noteworthy. Although high gold price levels currently support the profitability of e-waste recycling, price levels might as well decline in the future.

⁴² E.g.: New RoHS-compliant electronics with reduced concentrations of heavy metals, PBB and PBDE.

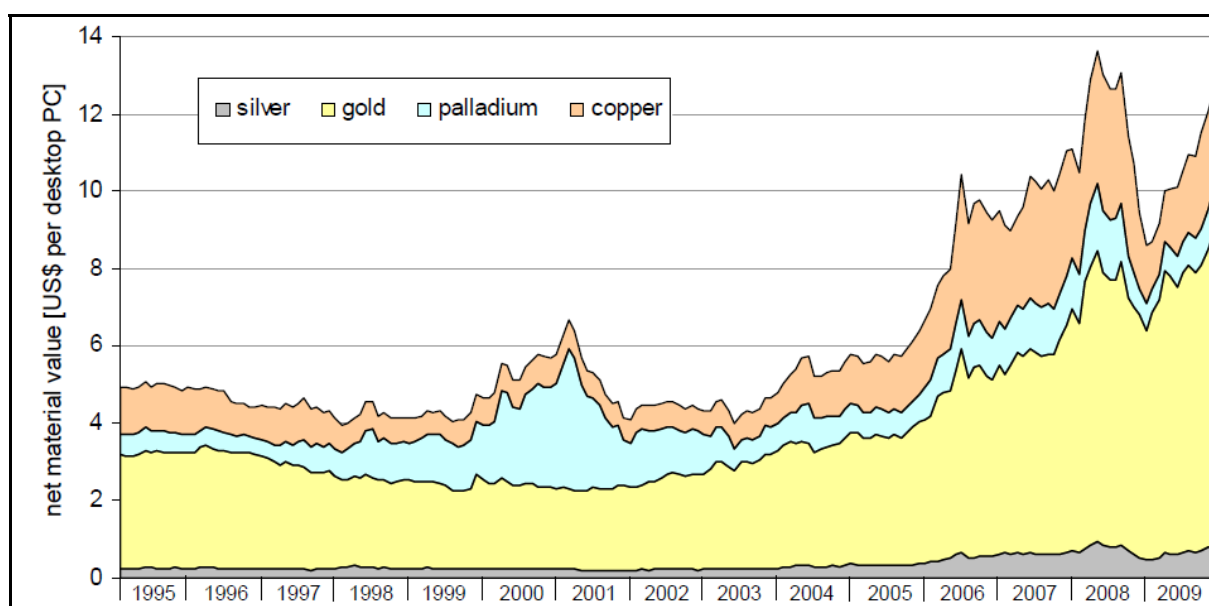


Figure 3 Net material value of the copper and precious metals content of an average desktop PC from January 1995 to October 2009 (Sources: Own calculations with data from Gmünder 2007 and LME 2009)

4.4.4 Dangers of indirect stimulation of illegal e-waste imports

The business models described in chapter 4.1.7 and 4.3.7 would lead to increased revenues for the Ghanaian e-waste recycling industry, which could also have effects on the problem of e-waste imports. If the economic benefits from e-waste would be increased, there might also be increased benefits for shipping used and obsolete equipment to Ghana. Although it seems unlikely that the recyclers themselves will actively participate in this transboundary trade, they might be willing to spend more for acquiring obsolete e-products – either collected from Ghanaian household and businesses or from other outlets such as the traders at Tema port. This premium will increase the revenues of traders that do not only import used goods, but also non-functioning equipment.

This possible stimulation of the e-waste imports are not only a problem because they contravene the Basel Convention, but also for environmental reasons: Even with improved e-waste recycling as proposed in this study, many processes and end-of-life management options still carry the risk of collateral pollution. This is particularly the case for the controlled incineration of plastics, the management of CRT-glass and other hazardous fractions. Although such impacts can hardly be avoided for domestically generated e-waste, imported e-waste should not be tolerated in Ghana at all.

5 Final conclusions and recommendations

The impacts of the currently practiced e-waste recycling on human health and the environment are significant and call for urgent action. The currently practiced informal e-waste recycling does not only lead to severe local pollution and negative health impacts for the people engaged in this sector, it also contributes to various local and global environmental problems such as the emissions of heavy metals and persistent organic pollutants, global warming and ozone depletion. In order to solve these problems, business and policy approaches must be launched and synchronised to address the various problems and root-causes of the current situation. The following chapter proposes principles and activities that should be endorsed and implemented by the government, the Ghanaian and international recycling industry and international donors aiming to support Ghana in its efforts to solve the e-waste problem.

5.1 General recommendation to policy-makers and the Ghanaian recycling industry

Incorporate the informal sector in future e-waste strategies

The informal sector is a key player in e-waste recycling in Ghana. It is already very active in the collection and pre-processing stage. Efficiency is already high in house-to-house collection of e-waste and the recovery of steel and aluminium. The informal collection and recycling sector provides employment for approximately 6,300 to 9,600 people countrywide, mostly to the people originating from the economically disadvantaged northern parts of the countries. The informal sector activities – despite its adverse impacts on human health and the environment – therefore provide both, a nucleus to develop a more advanced recycling industry, and important income opportunities for poor people. Any strategy addressing the Ghanaian e-waste management should therefore carefully consider the possible roles of the informal sector before establishing a parallel system in competition to the informal recyclers. In particular, it is recommended that those people that are currently engaged in informal e-waste collection and pre-processing become an officially acknowledged part of the recycling chain.

Deploy manual labour for pre-processing

The comparison between the presently applied recycling techniques in Ghana and the technologies applied in European countries reveals that European solutions are only partially applicable in the Ghanaian context. Especially pre-processing machinery developed and applied in Europe is often optimised to reduce labour costs rather than maximising resource efficiency. Under the socio-economic conditions of Ghana, recycling can make use of much more manual labour, which can be beneficial in economic, environmental and social terms. Although investments into machinery parks often appear to be attractive solutions, this is not necessarily the case in e-waste management in Ghana. Although some types of machinery

like CFC-recovery units for refrigerators and air conditioners, fume hoods for CRT-treatment and electric or pneumatic tools for dismantling are required to improve e-waste recycling, large scale shredder and mechanical sorting facilities are counterproductive and would lead to job losses. Therefore, any approach to improve e-waste recycling in Ghana should make use of the abundant labour force instead of deploying expensive shredding and sorting machinery.

Support and maintain international recycling co-operations

The improvement potential described in chapter 4 mostly requires international recycling co-operations. Although there are many recycling steps that can be carried out within Ghana, certain refinery processes – especially those for precious metals – need to be carried out in high-tech-facilities that are only available in very few countries. As these facilities require investments of several billion US\$ and waste volumes, much larger than those available in Ghana and its neighbouring countries, it is currently not a realistic option to establish such a facility in Ghana. It is therefore recommended that Ghanaian recyclers interlink with international recycling companies and networks to develop market outlets for their pre-processed e-waste.

Focus on high quality recycling products

Ghanaian recyclers have remarkable opportunities in the pre-processing phase of electronic products such as computers, DVD-players and hi-fi-systems. Here, recycling outputs could achieve market prices that are beyond the average unit prices achieved by European pre-processors. High qualities can be achieved by thorough deep dismantling and sorting of these products. Ghanaian e-waste recyclers should focus on these quality aspects to occupy this niche market.

Develop regulative framework

A key problem of Ghanaian e-waste recycling is cherry-picking. Fractions with high material value are recovered and sold, while hazardous fractions with low material value such as CRT-glass and plastics containing brominated flame retardants are dumped or burned uncontrolled. Even with implementing international recycling co-operations in the field of precious metals recovery, the problem of cherry-picking is not automatically solved. For recyclers, a sound end-of-life management of hazardous fractions will always be more costly than uncontrolled dumping or burning. Even if cost-efficient solutions like co-incineration of plastic in cement kilns can be identified, this would still imply additional transport costs for recyclers. Therefore, environmentally sound e-waste recycling is dependent on a sound regulatory framework that includes the obligation to care for all e-waste fractions. Naturally, such regulatory framework also needs stringent implementation and regular inspections.

Develop appropriate finance mechanisms

Although the net material value of some e-waste types can contribute to cover the costs for a sound management of low value and hazardous fractions, the example of CRT-devices shows that it will be very difficult to achieve environmentally sound end-of-life management without additional financing mechanisms. One solution could be the implementation of the principle of extended producer responsibility (EPR) by raising a fee for every e-product entering the Ghanaian market through import. As in Ghana, the demand for e-products is widely covered by the import of second-hand goods, this fee would also be applicable to the importers of this equipment.

The fees could either be distributed to the e-waste recyclers or be used to facilitate sound end-of-life management options, such as the establishment and maintenance of a disposal site for hazardous waste.

This financing mechanism should also take into account the likelihood that resource prices can fall to levels that make material recovery of e-waste unattractive from an economic perspective. In this case, sufficient financial resources must be available to further ensure a proper end-of-life management of whole e-waste.

Provide solutions for locally generated hazardous waste

There is currently no infrastructure like cement kilns, waste incinerators and hazardous waste disposal sites for the management of hazardous waste in Ghana. Nevertheless, such infrastructure is indispensable to provide local solutions for hazardous e-waste fractions. Therefore, Ghana should strive to develop such infrastructure in line with local and national development efforts. In particular, establishing a well managed hazardous waste disposal site should receive priority as it could provide end-of-life management solutions for many hazardous waste fractions simultaneously. As mentioned before, the costs for establishing and maintenance could partly be covered by appropriate e-waste financing mechanisms.

Regulate the import of used products

The socio-economic survey clearly revealed that the refurbishing of e-products is an important economic sector in Ghana. Besides providing income for an estimated 14,000 to 24,000 people, it helps to supply the Ghanaian society and industry with affordable second-hand equipment. As this sector sources a large percentage of its devices from Tema harbour, it is inevitably interwoven with the transboundary trade of used and end-of-life e-products. The trade currently comprises all, functioning, non-functioning but repairable, and non-functioning and non-repairable equipment. Although a complete ban of all second-hand imports seems inappropriate, Ghanaian decision-makers should define a clear boundary between the types of equipment acceptable, and those types and qualities unacceptable for imports.

Besides reducing the volumes of imported hazardous waste, this measure is also considered to be a pre-requisite for the long-term success of international recycling co-operations:

Especially in the field of CFC-recovery and destruction, it would be unacceptable if recyclers in Ghana would earn money from managing end-of-life devices directly imported from Europe: As the environmentally sound management is obligatory in Europe and already financed by producer responsibility schemes, the end-of-life management in Ghana would abuse this system and would subsequently damage the recognition of the Ghanaian recycling efforts. In this context, the recent ban on imports of CFC-refrigerators is an important step towards a responsible national e-waste strategy.

Similar efforts should be undertaken for obsolete and outdated electronic equipment and other appliances.

5.2 Specific recommendations for pilot follow-up activities

In order to facilitate the implementation of the proposed applicable recycling technologies, it is recommended to set up an e-waste recycling pilot project in Ghana. This project should help to overcome some of the current obstacles for improvements. It should closely work together with the Ghanaian authorities, the local recycling industry and international recycling networks to achieve sustainable solutions, to test and implement the business models elaborated in chapter 4 and to strive for a sound implementation of social and environmental standards to maximise socio-economic benefits. Generally, it is recommended that such pilot activities should focus on e-waste types that are not yet covered by any specific project activity in Ghana. In particular, refrigerator recycling, which is already well addressed by a UNDP-project, should not be primarily targeted. Naturally, synergies between the various projects should be tapped in order to increase leverage and coherency.

The following recommendations are meant to sketch some important principals that are considered crucial elements of a possible pilot implementation project:

Use EPA-Ghana as umbrella organisation

The pilot project should be formally attached to EPA Ghana to ensure coherency with ongoing policy-making processes on e-waste issues. Furthermore, such a structure will facilitate that lessons learned from pilot activities are fed into the administrative decision-making process.

Additional key stakeholders, such as the Agbogbloshie Scrap Dealers Association should be part of the project activities.

Conduct pilot operations in or close to existing recycling clusters

In order to make use of the dynamics of the existing informal recycling industry and provide a showcase on how to improve business operations, the project's physical recycling activities should be carried out within or close to existing scrap metal markets such as Agbogbloshie. This geographical proximity would also avoid pilot activities being regarded as competition by informal sector recyclers.

Give priority to directly linking Ghanaian recyclers to international recycling networks

As elaborated in chapter 4.1.7, the socio-economic benefits of international e-waste recycling co-operations can be maximised by establishing direct links between the small scale recyclers in Ghana and international refineries for copper and precious metals.

From an organisational perspective, the feasibility of establishing a co-operative should be discussed with all relevant stakeholders. The possible co-operative structure must ensure that all members will benefit from the economic gains, and additionally will be linked to the information flow regarding health and safety issues, knowledge transfer and market prices.

If a co-operative structure of this kind cannot be established, intermediaries conducting the trade with scrap metals and e-waste fractions should be supported. In this case, efforts should be evenly distributed to various trading businesses in order to prevent monopoly structures.

Improve social standards

Although some of the business models proposed in chapter 4 will lead to higher incomes for Ghanaian recyclers, this does not automatically solve the social problems of the sector. There is still the need to ensure that additional revenues are shared in a way so that also the most vulnerable groups in the recycling chain can improve their living and working conditions. Additionally, mechanisms must be introduced that secure the penetration of skills and know-how on issues regarding health and safety, improved recycling technologies and market prices and access.

Ensure rapid cash-flow

Most of the identified economic improvement potentials feature a severe obstacle for small scale recyclers in Ghana: In contrast to the currently practiced recycling approaches, they yield revenues with a delay of several months. As most people engaged in e-waste recycling live with less than US\$ 2 per day, it is of utmost important that also alternative business models can guarantee them a rapid cash flow to secure their daily demands. This can be achieved by appropriate micro-finance systems.

Focus on all e-waste fractions

Pilot projects should not only focus on the high value fractions such as PWBs, but also search for solutions for hazardous and low value fractions such as CRT-glass and plastics. These solutions could use local infrastructure and installations such as cement kilns, hazardous waste disposal sites and the construction industry. Each identified solution should be supported by appropriate tests and risk analysis to minimise environmental impacts and to prevent cross-contamination.

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Annex I: SLCA-Assessment Sheet for Informal SMEs

Introduction

The following Assessment Sheet is aimed to support the collection of socioeconomic data and information in a structured way. It transforms the SLCA-indicators into various clusters / topics that should be filled with information. The assessment shall be done by a combination of structured interviews and visual inspections. In previous assessments, it proved useful to roughly follow the content and chronology of the Assessment Sheet during the interviews. Nevertheless, building up trust is important in such assessments so that interviews should be carried out in an informal and flexible way. It is up to the interviewer and dependent on the general situation if the collected information is filled in right during the interview or whether the interview is conducted orally without taking notes. In the latter case, it is recommended to fill in the information right after the interview is carried out. Please use clearly readable handwriting!

If accepted by the interviewed enterprise, photographs can be used to support the observations.

In cases where the required level of trust and transparency is not achieved during the interview, the assessment does not have to be pushed beyond what is acceptable for the interview partners. Instead, the assessment should rather focus on some few aspects and visual inspections.

GENERAL INFORMATION

Date of assessment:

Name of conductor(s):

Name of enterprise:

Location of enterprise:

Address:

Phone number:

E-mail:

Name of owner:

Name of manager:

GENERAL BUSINESS INFORMATION

Type of business

Describe the main business activities and add information on possible side-businesses.

Example: Enterprise xyz is active in the refurbishment and resale of used mobile phones. It purchases used and obsolete mobile phones from internationally operating dealers in order to serve the local market. Enterprise xyz passes its products (functioning mobile phones) to a loose network of street vendors. As side business, the company sells scrap mobile phone parts (those turning out not to be repairable) to local waste dealers.

Workspace description

Describe the area (room / hall / backyard) where the business operations are conducted. Include information on illumination / lighting and aeration / ventilation.

Example: The repair activities are carried out in a small hall (about 10 x 5m) equipped with 5 desks for repair operations. The spare parts and the waste are stored in buckets and sacks on the floor and around the desks. The hall has 4 windows on one side, which provide good daylight for about half of the room. The back of the room is illuminated by some light tubes. Because the windows and the door are normally left open, the hall is well aerated.

Production processes & technologies

Give a description of the applied technologies and processes used in the enterprise. Also describe the type of tools and machines used for these processes. Include information on implemented health protection measures.

Example: The repair of mobile phones is carried out with quite simple tools like screwdrivers and soldering irons. For most repairs, workers have to exchange and load the battery, clean the contacts, the display and the housing with cleaning liquid and partly exchange some electronic components by unsoldering the damaged parts and putting in new components. For health protection, the management offers respiration masks. Because of the hot indoor temperature, most workers do not like the masks and work without them.

Health & safety issues

List and describe obvious health and safety risks from the carried out operations. See Annex II for a rough checklist to identify possible health and safety risks. In addition, check on other less specific risks (e.g. accident risks from heavy machinery, risks from poorly maintained electricity wiring). Try to elaborate on possible health problems that workers might blame on their professional activities.

Example: Health and safety risks might stem from the soldering operations. As the workers are bowed over their repair desks, they frequently inhale the fumes from the soldering operations. One worker claimed that – after a long day of soldering operations – he feels a stabbing pain in his lungs.

Business outputs

Try to quantify the enterprises' monthly / annual production in absolute and monetary terms.

Example: The enterprise repairs approximately 800 mobile phones per month. They are sold to the street vendors for \$ 5–10 per piece, depending on the quality. The revenues from scrap mobile phones are negligible and may sum up to \$ 50 per month. On average 1000 waste mobile phones are sold to scrap dealers per month.

Business inputs

Try to quantify the enterprises' monthly / annual business inputs needed to generate the described outputs. Focus on materials and running costs (no investments into machinery or others)

Example: The enterprise purchases between 1500–2500 used and obsolete mobile phones per month, which cost between \$ 0.50 and 1.00 per piece, depending on the quality and condition. Amongst these mobile phones are also many unrepairable devices, which are important sources of spare parts. The enterprise uses approximately 2–3 mobile phones to produce a functioning one. Besides mobile phones, there are little further materials needed: Solder, cleaning liquid, glue and batteries, which are purchased on the local market. These additional costs sum up to less than 50\$ per month.

Ownership and rent

Collect information on the ownership of the used business facilities. If rented, give figures on the weekly, monthly or annual rent.

Example: The house the business is located in belongs to a local investor who owns large part of this business quarter. The rent is \$ 75 per month.

Taxes and fees

Collect information on official and unofficial taxes or fees.

Example: The business owner pays \$ 200 taxes to the local administration annually. The tax is collected by an administration representative. Additionally, the business pays \$ 10 to the local market association per month.

INFORMATION ON STAFF AND EMPLOYMENT

Number of employees / workers

Give figures and differentiate between different tasks and hierarchy levels.

Example: Enterprise xyz employs 8 persons (not counting owner and manager): 1 person takes care of management and financial issues, but also engages in the repair of mobile phones if necessary. 6 people are fully occupied by repair and refurbishment of mobile phones. 1 person (a low skilled youth) is employed for conducting daily necessities like cleaning tasks, shopping of basic goods and food and the delivery of mobile phones to some customers.

Level of required skills

Give a description of skills required for this business. Focus on the skills needed for the key business activities.

Example: The repair of mobile phones generally requires a high level of technical knowledge. Two of the employed people have a University degree in electronics engineering and are therefore the people instructing new workers and taking over the more complex repair tasks. The majority of repairs can be carried out by people with average education (elementary school education) after detailed instructions and some practical experiences. Nevertheless, it is mandatory that repair personnel have good eyes and are skilled in handling small parts and components.

Employment status

Type of employment (differentiate between people with formal working contracts, people with oral agreements and people with other arrangements)

Example: Besides the 2 persons with university degrees, none of the workers hold formal contracts.

Caution: The topic is partly sensitive. It might be better to address more indirectly after having built up some trust. Workers can serve as valuable source of information.

Sex- and age-distribution

Give information on the sex- and age-distribution of personnel (this section can also be based on observations).

Example: Only men are working in the enterprise. Most men are aged around 20 to 30. One of the repair personnel appears to be older than 45.

Social security

Collect information on possible (official and unofficial) mechanisms in case of illness, pregnancy / maternity leave, unemployment, retirement or any other case of social difficulty.

Example: None of the employees are covered by any social security system. Also those employees that hold formal contracts have no kind of social insurance like health or unemployment insurance or old age pension. In the past, the owner of the enterprise gave some financial support for medical treatment of his employees.

Education & Apprenticeship

Describe possible apprenticeship- and training mechanisms. Include information on the financial and social conditions of apprentices and staff on training.

Example: Usually an apprentice is in the enterprise for 1 or 2 years, depending on his speed of learning. During that time, the apprentice works for free, but is given free housing and catering. Additionally, he receives a considerable amount of tools and a small budget to start up his own business after his education. Normally this start-up-package is worth around 300\$. In the past, most apprentices did not start their own businesses but stayed with the enterprise as paid technicians. In addition to this apprenticeship system, technicians also receive trainings on an irregular basis. Normally training is given when technicians are confronted with new technologies so that they have to build up their technical knowledge as well. Usually, this kind of training is organised by the market association and lasts 1 or 2 days.

Salaries

Collect information on the salary / income of the various staff members, including the type of payment and possible variations of income (e.g. advance payment, performance-linked payment, bonus- malus-systems)

Example: The repair personnel are paid per outcome: For each repaired mobile phones, a persons receives a certain amount of money from the enterprise (\$ 0.50 for normal repairs, \$ 0.75 for difficult repairs). The money is paid to the workers on the end of every month. If a worker damages a valuable mobile phone or an important working tool, the resulting losses are deducted from his salary.

Caution: This topic touches sensitive issues. Therefore this section should be addressed more indirectly after having built up a certain level of trust. Be aware that workers may serve as alternative information sources.

Salaries in relation to living expenditure

Collect information on whether the salaries are sufficient to secure a basic living standard (housing, food, transport, clothing, medication, education, social participation). Besides the subjective statements of the employees, the introduction of a proxi-indicator might be useful. One proxi-indicator could be the question on school fees: 'Is the salary enough to cover the school fees for the children?' Although the answer depends on a variety of factors, including the number and age of the children, it might be an interesting means to verify initial statements.

Example: The employees are mostly satisfied with their income. Although they claim not to be rich persons, they are all able to afford a certain standard of living including some prestige goods like large flat-screen TVs or motorbikes. For all staff, the earnings are sufficient to cover the school fees for their children.

Working hours

Collect information on average daily, weekly and monthly working hours, including information on daily and weekly rest periods and annual paid and unpaid holidays. Also include information on working time in peak seasons (overtime) and low seasons (e.g. underemployment).

Example: From Monday to Saturday, workers and management normally start working at 8am and finish at 5pm. Sunday is off. There is a 1 hour lunch break and two or three 15 minute breaks for smoking and tea distributed over the day. In peak seasons (after purchasing a new batch of used mobile phones, work typically continues after a 1 hour dinner break and lasts until 10 or 11pm. In turn, work in low seasons is quite relaxed with many workers only working half day. Apart from the official holidays (national holidays, religious holidays) there is no paid holiday in this enterprise. Nevertheless, employees can take some days off in cases of emergency (e.g. family reasons, health reasons). This kind of leave is normally unpaid.

Employment turnover

Give information on the typical length of the employments

Example: The repair personnel are typically working for the enterprise for long terms. One engineer is working for the enterprise since its foundation in 2002. All others were employed as the enterprise grew bigger. Only one engineer suddenly didn't turn up again. Maybe he found some other job or returned to his home village.

Job satisfaction

Collect information on the employees' satisfaction with their business.

Example: The workers employed in the enterprise consider their jobs as quite prestigious as they consider them as somehow 'close to high-tech'. Additionally, the jobs are relatively safe and better paid than other available jobs in this region.

INFORMATION ON THE BUSINESS SECTOR

General sector information

Collect information on the size, structure and functioning of the sector

Example: There are numerous mobile phone repair shops in this town. The area around harbour market is one of the two local centres of this industry. The other centre is located in the western outskirts of town on the road to Ruwade. Most repair shops are much smaller than this one (only 1 or 2 people), but there are also 5 or 6 enterprises of roughly the same size. Most of the small repair shops are not registered. This repair shop and some of the bigger competitors are the only official mobile phone repair enterprises in town. In addition, there are around 100 computer repair shops around harbour market. But these repair shops do not engage in the mobile phone business.

Information on upstream sectors

Collect information on the size, structure and functioning of upstream activities

Example: The used and scrap mobile phones purchased for the repair business are sold by some few dealers that have their offices in the harbour area. These dealers not only trade with used mobile phones, but also with other used goods like furniture, computers and cloths. Most of the traded goods are imported via the harbour.

Information on downstream sectors

Collect information on the size, structure and functioning of downstream activities.

Example: The repaired mobile phones are mostly sold to a loose network of street vendors. The enterprise serves about 20 vendors that mostly focus on mobile phones, but also sell other products (e.g. batteries, calculators). Another group of roughly 20 vendors purchase mobile phones on an irregular basis. These vendors mostly run small shops with a broad variety of goods. The scrap from unrepairable mobile phones is sold to one scrap dealer who runs a recycling operation close to the harbour.

INFORMATION ON THE LOCATION AND THE NEIGHBOURING COMMUNITIES

The following section addresses the surrounding of the assessed enterprise. Apart from interviews, visual inspections should be used for information collection.

Local setting

Describe the location in which the enterprise is operating. Include information on the local social set-up, the population density and other types of businesses.

Example: The enterprise is located in a densely populated quarter. Cheap one- or two-floor buildings dominate the quarter, which is mainly populated by people that just recently moved from the country into the city. The quarter's main business sector is the repair and resale of electronic equipment (mobile phones, TVs, electric fans, computers, refrigerators). While the main traffic routes are flanked by shops and populated by street vendors, backyards are used for repair activities. There are still some small agricultural areas. There, corn and vegetable is planted for local consumption. Nevertheless, farming is only a side business of some few people.

Water supply & sanitation

Give information on the water supply and sanitation of the enterprise

Example: The enterprise is connected to the city's water supply and sanitation system and has 4 taps and one toilet.

Waste management

Give information on the waste management practices. Especially address the waste stream that is generated by the assessed enterprise.

Example: Household waste and waste generated by the repair businesses are collected by collectors and transported to a nearby field where the waste is sorted. Valuable fractions like metals and plastic bottles are sold to waste dealers. Other fractions are disposed on one side of a field and the banks of a small waterway. There are many youths and children amongst the collectors.

COMPLEMENTARY INFORMATION

Add any other complementary information / impression collected during the assessment. Note any additional information that might be of interest.

Example: The relation between the manager and his staff seemed to be very friendly. The mutual support and trust between employees and management seemed to be strong. The manager also seemed to be interested in exploring new business niches, where he could earn additional profits without neglecting his core business. Once the manager mentioned that the direct neighbours complained about the smoke from the plastic waste that was formally burnt in the backyard of the enterprises. Now the enterprise does not burn waste any more but sells everything to a waste dealer.

Annex II: Checklist to identify health and safety risks

Checklist for obvious health and safety risks during the refurbishing and recycling of electric and electronic equipment.

Product / component	Health hazards during refurbishing and recycling operations
Printers & toner cartridges	Emissions from toner dust and ink. Direct contact with toner dust and ink should be avoided.
CRT-monitors	Damage to the tube leads to the emission of hazardous dust. In addition, CRT-glass is penetrated with lead so that broken and pulverised CRT-glass might cause lead emissions.
LCD-monitors (flat screens)	Damages to the backlights of the screens can lead to the emission of mercury.
Electric and electronic equipment in general	Fumes from soldering operations (these fumes should not be inhaled)
Plastics from electric and electronic equipment	Most plastics from electric and electronic equipment are penetrated with partly hazardous flame-retardants. Therefore melting and burning of these plastics releases substantial amounts of hazardous substances. Additionally, dust from breaking and crushing of plastics can lead to the emission of hazardous dusts.
Copper-containing parts in conjunction with plastics	In order to recover copper, the burning of copper containing parts and cables is quite widespread in many countries. During burning of plastics and especially PVC, significant amounts of hazardous substances are emitted.
Printed circuit boards	In some countries, recyclers extract precious metals from printed circuit boards by acid leaching. This process holds many health & safety risks.
Batteries of electric and electronic equipment	Damages to batteries can lead to the emission of hazardous substances.