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e-Waste Treatment Facility in Uganda Economic Feasibility Study

Final Report, February 2014

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Executive Summary

To address the issue of Waste Electrical and Electronic Equipment (WEEE) or e-waste in Uganda the United Nations Industrial Development Organization (UNIDO) aims at the implementation of a manual e-waste treatment facility in Kampala, Uganda. As a first step this report presents an economic feasibility study as a basis for the subsequent development of a detailed business plan for a manual e-waste treatment facility.

The feasibility study is based on model calculation with the purpose to roughly estimate all relevant financial flows which occur during the operation of the business and to identify key processes and parameters reacting sensitive on changing conditions. In the sensitivity analyses, the parameters are varied one by one to assess their impact on the economic business performance in comparison to a baseline scenario that served as a reference. The baseline scenario describes realistic conditions based on expert judgement. It represents the current conditions in Uganda and on the global market as assessed during this and previous studies.

Results suggest that under the current local and global economic conditions the e-waste treatment facility in Kampala cannot achieve an economically self-sufficient business if solely relying on the intrinsic value of the treated material. In the baseline scenario, the business doesn't break even, also not if higher collection rates are achieved. In contrary, at a throughput of 1'000 t/y a deficit of -250'000 USD is made and every increase in the collection rate leads to an increase in the deficit. This is mainly due to two cost factors, which stand out from the others with regard to their significance: the **purchase prices for e-waste** that are paid to incentivize collection and **the costs for the treatment of cathode ray tubes (CRTs)**. In case the business could access further income streams to cover the high purchase costs of waste material or the CRT treatment costs, respectively, the business could be profitable. This implies that financing mechanisms must be available, e.g. a financing of non-profitable fraction or subsidizing the purchasing price of waste material. Since the latter solution works for B2B collection at the most it is recommended to set up a **flexible and adequate financing scheme** targeting at paying for the treatment of the problematic fractions, such as CRTs. It is expected that CRTs remain a challenge for e-waste management in the mid-term, since CRTs are still the dominant screen technology in use in Uganda and hence will appear in relevant volumes in the waste stream over a longer period.

A relevant issue for the business is the difficult transport situation for waste fractions destined for the regional or international market. Transport is cost- and time-consuming given that Uganda is a landlocked country and that several border crossings are required which generally entail a considerable bureaucratic effort. This study also demonstrates that volatile commodity prices (e.g. significant price drop of various metals in 2013) also pose a risk to the business, which in turn supports the idea of a flexible financing mechanism. Furthermore the sensitivity analyses revealed that a deep dismantling is favourable for the business not solely in environmental and social, but also financial terms. Thereby, a wage rise from 120 (baseline scenario) to 150 USD/month for the dismantling staff does not significantly affect the business performance. The rather low impact of the paid salaries on the overall financial performance will second the facility in paying fair salaries.

Another aspect to take into account is securing the **cash-flow** of the business. Several valuable materials like printed wiring boards (PWBs), processors, batteries, etc. can only be sold when a required minimal volume is gathered (minimal lot sizes). These unsold materials thus hamper the cash flow of the business. A strategy to avoid long-term interruption of revenues is to cooperate with similar projects at a regional level and gathering PWBs from several treatment facilities in a regional hub, which should allow to gather the critical volumes in a shorter time frame. Since a regional cross-frontier solution could raise strong resistance from the authorities, there is need for coordination and awareness building on a regional policy level.

Based on this analysis it is concluded that a sustainable e-waste treatment business can only grow in Uganda in combination with a comprehensive framework, which ensures:

1. that business sustainability is guaranteed under both favourable and unfavourable economic conditions. I.e. an additional flexible income stream enabled through a financing scheme needs to be established for periods in which the intrinsic value of the treated material is not sufficient for a break-even. Additionally, a seed-funding or providing grants in the initial phase of building up a business might be required;
2. that e-waste businesses can grow in a level playing field. I.e. that rules set by legislation and standards, as well as monitoring and control mechanisms favour high standard operations;
3. that market incentives are set such as high collection and treatment rates are encouraged. I.e. appropriate collection processes need to be attracted, ensuring that high volumes of both valuable and non-valuable waste materials are collected equally and that those materials reach appropriate treating facilities.
4. that regional cross-national cooperation models are supported in order to gather critical volumes of e.g. PWBs. I.e. these models should allow e-waste businesses to participate on the global market for a maximal return of value for secondary raw materials, which also requires that government bodies guarantee a smooth, reliable and timely handling of export licenses and other administrative procedures to facilitate exports of certain e-waste materials.

Table of Content

1 Introduction

Similar to the global markets, the consumption rates of electrical and electronic equipment (EEE) have accelerated in Africa in the last decade. As a consequence, the volumes of waste originating from those appliances, generally known as Waste Electrical and Electronic Equipment (WEEE) or e-waste, have risen significantly. To date, Africa is lacking appropriate infrastructure to treat e-waste in a controlled manner and most activities in this field are performed by the informal sector. This leads not only to a high loss of valuable resources comprised in e-waste, but to severe environmental and health issues due to the inadequate treatment procedures applied.

To foster the proper management of e-waste in Uganda, the United Nations Industrial Development Organization (UNIDO) aims at the implementation of a manual e-waste treatment facility in Kampala. Empa[1] – the Swiss Federal Laboratories for Materials Science and Technology – in cooperation with the Austrian "Demontage- und Recycling-Zentrum" (D.R.Z.) has been mandated by UNIDO to contribute its experience in the field of e-waste, among others with an economic feasibility study. This study assesses financial aspects of e-waste recycling in Uganda.

1.1 Objectives

The main objective of this study is to assess the financial feasibility of an e-waste treatment facility in Kampala, Uganda. It aims at providing a basis for the subsequent development of a detailed business plan for a manual e-waste treatment facility. To this end, a sensitivity analysis for different crucial parameters (i.e. wages, e-waste bulk composition, collection strategy) is conducted. The tool for this study is an Excel-based business model.

The study encompasses appliances of the WEEE categories[2]: small household appliances (cat. 2), IT and telecommunications equipment (cat. 3) and consumer equipment (cat. 4). The focus is set on the following appliances:

- desktop PCs (cat. 3),
- IT accessoires (cat. 3),
- CRT and LCD monitors (cat. 3),
- laptops (cat. 3),
- printers (cat. 3),
- and CRT and LCD TVs (cat. 4).

[1] www.empa.ch, www.ewasteguide.info

[2] See classification according to the EU WEEE Directive 2002/96/EC: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0024:0038:EN:PDF

2 Model Development

2.1 Model Description

The model calculates the relevant financial flows in an e-waste treatment facility based on a defined throughput of e-waste. It thus combines the features of a business model and a mass flow model. The model covers the processes collection, dismantling and supply to downstream processes. Basically, calculations are based on (1) the input into the model (WEEE volumes and composition), (2) the material composition and (3) the effort to dismantle the WEEE the required investment and running costs as well as the generated income due to material sales (Figure 1).

The purpose of the model is:

1. the estimation of all relevant financial flows which occur during the operation of a local e-waste treatment facility, and
2. the identification of key processes and parameters reacting sensitive on changing conditions ('what is the economic performance of an e-waste treatment facility under changing framework conditions?').

The model is based on previous business plan calculations developed by D.R.Z[3] and KERP[4] and the economic feasibility studies conducted by Empa for Morocco and Tanzania (Blaser and Schluep 2011; Blaser and Schluep 2012).

The design of the model enables the inclusion of the following appliances of the EU-WEEE directive:

Table 1. Appliance scope of the model.

Devices (name in the model)	description	WEEE cat.
Small household appliances kettle	Kettles	2
Small household appliances cloths	Irons	2
PC/ Server	PC towers (CPU – Central Processing Units), servers	3
Notebook	Notebooks/laptops	3
Printer/Scanner/Copier	Printers, scanners, copying machines	3
IT accessories	Keyboards, mice	3
Mobile phone	Mobile phones incl. recharger	3
CRT monitor	CRT monitors of PCs	3
FPD monitor	FDP (flat panel display) monitors of PCs	3
Audio appliances	CDs/Radio recorder (ghetto blasters)	4
Video appliances	DVD-players	4
CRT TV	CRT TVs	4
FDP TV	FDP TVs	4

To approximate realistic conditions, the most important assumptions and parameters are based on the draft of the inventory on e-waste management practices in Uganda (Ssebagala, Wasswa, and

[3] Demontage Recycling Zentrum; http://www.drz-wien.at/index.php?id=17

[4] KERP Kompetenzzentrum Elektronik und Umwelt; http://www.kerp.at/

Schluep 2013), a data inquiry conducted by the Uganda Cleaner Production Center (UCPC) and the experiences made at D.R.Z in Vienna. For details see chapter 2.2 and 2.3.

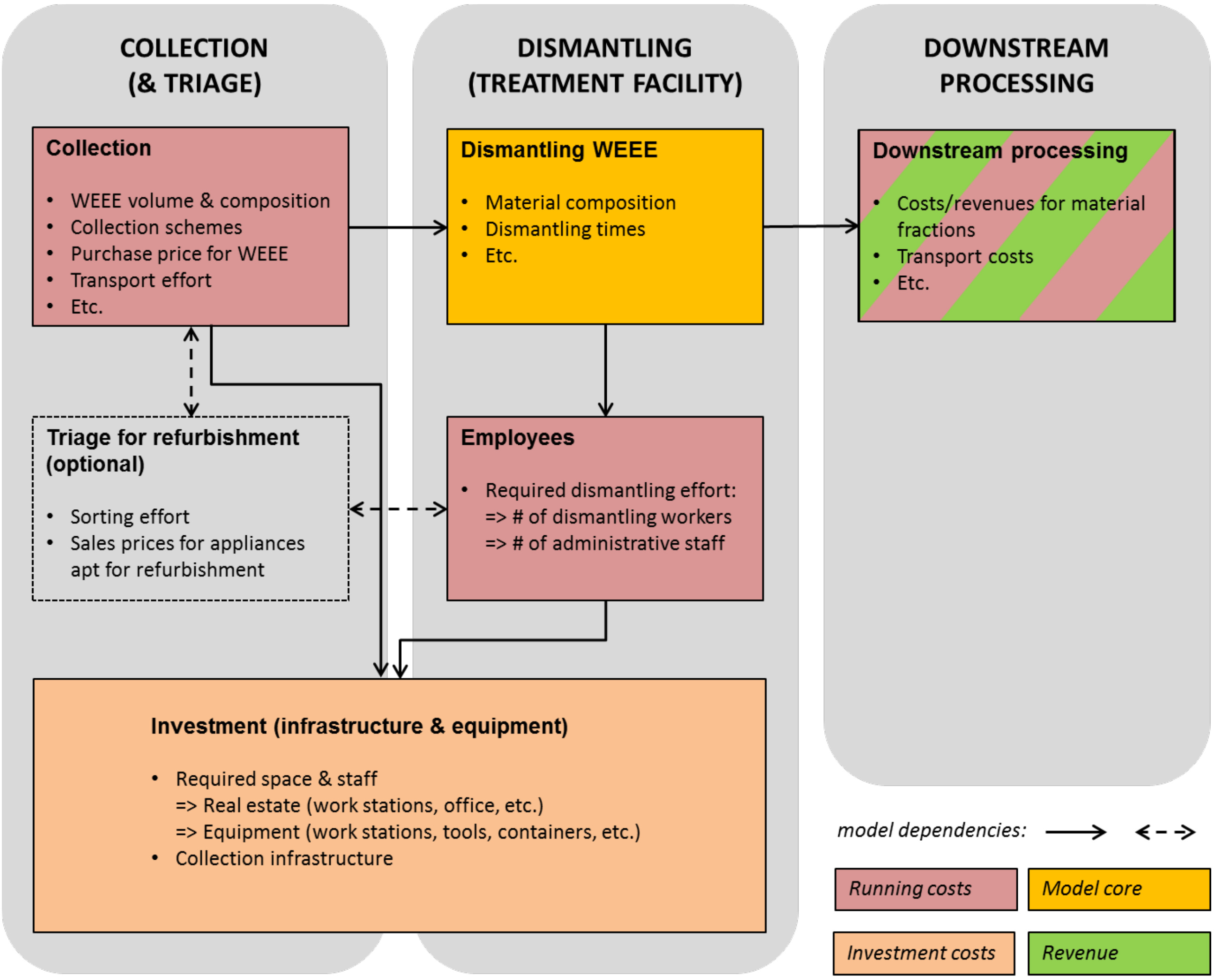

Figure 1. Simplified schema of the model, including the main processes reproduced by the model and their main parameters.

2.1.1 e-Waste Treatment Facility

The core of the model is the manual dismantling unit of the e-waste treatment facility. The model considers both the financial flows and the (e-waste) material flows into, within and out of the facility.

Given a certain e-waste input into the model (WEEE volume & composition), it calculates the respective output of 31 different materials and the required effort, infrastructure and equipment for this process. This calculation is based on data gathered during batch dismantling of each appliance at D.R.Z. (material composition and dismantling times). Different dismantling depths can be taken into account (A = superficial, B = medium, C = deep).

For the e-waste treatment facility, the following cost factors are taken into account:

- dismantling
  labour and non-wage labour costs, training costs, investment costs and depreciation for equipment
- administration
  labour and non-wage labour costs, investment costs and depreciation for equipment
- general infrastructure & equipment, CMR (cleaning, maintenance and repairing)
  investment costs and depreciation for real estate, hall, etc.; running costs for CMR

2.1.2 Collection

A special, because both difficult and decisive, process in the operation chain is the collection. In the model, it comprises:

- the acquisition of (W)EEE[5]
  purchase prices of the collected material (i.e. tender offers, to scavengers)
- collection and transport
  transport costs, costs for take-back points, labour costs, investment costs (truck, etc.)

The model offers 3 different schemes to collect e-waste:

1. **in-house collection (facility)**: e-waste can be handed in directly at the e-waste treatment facility in exchange of a remuneration. This scheme is mainly addressing persons from the informal sector (i.e. scavengers) and households.
2. **collection at collection points**: at different locations in the city a small collection point (container, attendant, etc.) is set up, where e-waste is accepted in exchange of a remuneration. This scheme is mainly addressing persons from the informal sector (i.e. scavengers) and households.
3. **B2B (business-to-business)**: the facility collects the e-waste directly from companies or authorities. It depends on the kind of agreement (tender offer, donation, etc.) if a price is paid and how much it is. This scheme is addressing companies and authorities.

2.1.3 Downstream Processing

The downstream processes refer to the processes subsequent to the treatment facility. These processes encompass the final treatment (i.e. recovery, disposal) of the materials generated at the e-waste treatment facility. Apart from reselling appliances which are still apt for reuse, the downstream processing is the only process which generates revenue. However, the disposal or environmentally sound treatment of hazardous materials occasion costs, too.

The model comprises the processes:

- transport
  transport and handling costs
- downstream processing
  costs and revenues for/from material recovery and disposal facilities

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[5] (W)EEE: this term refers both to WEEE (obsolete appliances) and EEE (here: appliances which can be reused).

2.1.4 Triage for Refurbishment (not calculated in this study)

Optionally, a module can be factored in for the model calculation that reproduces the triage (sorting) and onward sale of collected appliances which are still apt for reuse. In the present study this module was not applied.

When collecting e-waste, it is likely that a certain share of the collected appliances are still apt for reuse. The higher quality of those appliances (compared to the obsolete ones) rises the purchase prices that the treatment facility pays for the e-waste. The purpose of the module is thus to consider this circumstance and resell those appliances which are still in a condition to be refurbished. In doing so, the burden of the higher purchase prices are passed on and a meaningful reuse of the appliances is promoted (i.e. extend their life span, provide cheap appliances).

This module reflects the following processes:

- triage of the collected (W)EEE
  labour costs, investment in required infrastructure and equipment and depreciation
- sale of the refurbished appliances
  sales prices

2.2 Baseline Scenario

As a basis for the sensitivity analysis conducted with the model, a default value is set for different model parameters to create a baseline scenario. Starting from this baseline scenario, several relevant parameters are then varied to analyse the sensitivity of the overall economic performance of the business.

This "default setting" relies on a data collection conducted by the UCPC for this feasibility study, a draft report on e-waste practices in Uganda (Ssebagala, Wasswa, and Schluep 2013) and analogies to the situation and experiences in other African countries. The main parameters and assumptions of this baseline scenario are described below. Information on most parameters of the model can be found in appendix.

Table 2."Default" settings in the baseline scenario for relevant parameters.

Facility location	Kampala (between city center and suburbs), Uganda
Collection scheme	• 50% collected via B2B scheme (from companies & authorities) • 50% in-house collection at facility (incl. incentives for scavengers)
Commodity prices	Average prices for 2012 (Au, Ag, Pd, Cu, Fe, Al, Co, Ni considered)
Wage dismantling worker	120-140 USD/month[6] (+ 10% non-wage labour costs)
Dismantling depth	C (deep dismantling), see Table 17 and Table 18 in the appendix
Downstream processing	Focus on local markets and cooperation with regional e-waste hubs (amongst others due to low volume). See below.

[6] based on discussions about a "fair and reasonable" salary with the UCPC.

Table 3. Applied WEEE composition and purchase prices in baseline scenario.

		Purchase price for collection	
	WEEE composition	**Informal sector**	**B2B**
PC / Server	20.0%	-5.0 USD/unit	-6.0 USD/unit
Notebook	1.1%	-3.0 USD/unit	-3.6 USD/unit
Printer / scanner / copying machine	5.0%	-0.5 USD/unit	-0.6 USD/unit
IT accessories (keyboards, mice)	2.0%	-0.2 USD/unit	-0.24 USD/unit
CRT monitor	30.0%	-3.0 USD/unit	-3.6 USD/unit
LCD monitor	1.0%	-2.0 USD/unit	-2.4 USD/unit
CRT TV	39.0%	-5.0 USD/unit	-6.0 USD/unit
LCD TV	1.9%	-5.0 USD/unit	-6.0 USD/unit

The **composition of the WEEE** bulk that is collected is estimated based on previous studies in Morocco and Tanzania (GIZ 2010; Blaser and Schluep 2012), a field survey with scavengers in Uganda carried out by UCPC and the following assumptions:

- 15% laptops (of all computers)
- 1 printer per 2 PCs
- 10% LCD monitors / 90% CRT monitors
- 10% LCD TVs / 90% CRT TVs

The **purchase prices** refer to the price which is paid to the suppliers of e-waste (i.e. scavengers, households, companies, authorities) during collection. It is hardly possible to determine an exact price given that the price varies considerably depending on the appliances' quality, negotiation skills, etc. The purchase prices provided above were estimated based on experiences in neighbouring countries and adjustments relying on the material revenue calculated in the model. It should be noted that those prices refer to appliances which are obsolete (e-waste) and can't be reused. However, the purchase prices for the B2B scheme amount to 120% of the price paid to the informal sector, assuming that the e-waste from this source is of better quality.

Various treatment alternatives exist for the **downstream processing** of the materials generated at the e-waste treatment facility. The alternatives differ in terms of financial aspects or the place of destination, but also in aspects related to the quality of the treatment (e.g. environmental and social conditions in the respective enterprise). For economic reasons as well as for the compliance with environmental and social standards, a careful selection of the downstream processing destinations is therefore essential for the sound operation of a treatment facility. Another major criteria for the selection of the downstream processing destinations in the baseline scenario is the focus on local markets and the preferred cooperation with regional treatment companies (e-waste hubs). A major reason for this regional cooperation is to gather the respective required minimum lot sizes to supply materials (i.e. PWBs) to high-tech smelters. For information on the specifics of the downstream processing as well as the respective transport costs, please see Table 19 and Table 20 in the appendix.

2.3 Costs

The most crucial figures of costs that are considered in the model are listed in this chapter. Detailed figures can be looked up in the appendix.

2.3.1 Labour Costs

Because of the labour intensity of a manual dismantling facility, the wages paid to the workers are a financial factor of the business that is analysed in the study.

There is no minimum wage in Uganda. Based on information of the UCPC and experiences from other developing countries, the following wages are used in the model:

- Unskilled worker 120 USD/month
- Skilled (experienced) worker 140 USD/month
- Secretary 140 USD/month
- Driver 120 USD/month
- Administrator 500 USD/month
- Director (CEO) 1'000 USD/month

10% of non-wage labour costs were added to the respective wages.

2.3.2 Transportation Costs

Different types of transportation are required for an e-waste treatment facility, in particular if output materials are traded on the global markets. First, the collected appliances must be transported to the facility, then the generated output materials are distributed to the local markets as well as to national and international downstream processing companies. In this study, transportation by lorry, by train and by ship was considered (see Table 4).

For international transport, a transport by road is more expensive than a transport by train. Therefore no transport by road for international shipping is considered in the model.

Table 4. Transportation costs.

type	details	costs	Sources
road	urban collection, small truck	-1.8 USD/km	UCPC/J. Wasswa
train	Kampala - Nairobi	-2000 USD/container	UCPC & WorldLoop + own estimation
train & ship	Kampala - Nairobi (train) + Nairobi - Antwerp (ship)	-5'006 USD/container	UCPC & WorldLoop + own estimation

2.3.3 Downstream Processing Costs and Income

The supply of output materials to downstream processing companies either incurs costs or generates income. Table 19 in the appendix provides a complete overview of the prices and income per ton, respectively, which are paid for each material considered in the model.

One important factor to estimate the income which is generated are the **commodity prices** on the global markets. They determine the prices for materials like PWBs, processors, batteries, etc. Locally paid commodity prices in Uganda differ from the prices on the global markets. The following commodities can be sold locally in Uganda and hence the local prices are used in the model:

- Aluminium 1’000 USD/ton
- Scrap iron 250 USD/ton
- Copper 4’000 USD/ton[7]

In the model, the average commodity prices 2012 of Ag, Al, Au, Co, Cu, Fe, Ni and Pd are used (baseline scenario, see chapter 2.2.1). Table 15 in the appendix gives an overview of the fluctuation of the commodity prices between 2002 and 2012.

The precious metals (Au, Ag, Pd) are mainly concentrated on the **PWBs** and determine the PWBs’ trading price. The PWBs are a crucial fraction for the revenue of the facility. If supplied directly to integrated smelters, PWBs generate a particularly high revenue. However, as a rather large volume of e-waste has to be processed to make up the required minimum PWB lot sizes of the integrated smelters, the PWBs are supplied to an intermediary in Nairobi in the baseline scenario. A detailed compilation of the potential income is found in Table 19 in the appendix.

Li-Ion- and NiMH-batteries usually generate a revenue, too. Among the appliances considered, a large share of those batteries is found in laptops. According to Umicore Battery Recycling[8], the average distribution of batteries of obsolete laptops is approximately 87,5% Li-Ion and 12,5% NiMH batteries. The prices of the batteries are based on the commodity prices of cobalt (Li-ion) and nickel (NiMH). Depending on whether the batteries are directly supplied to an integrated smelter or supplied to an intermediary, the prices vary considerably (see Table 19 in the appendix).

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[7] According to the UCPC field survey a copper price of ~250 USD/ton (stripped cables) was offered on the local market. This is very little for copper, probably due to the absence of a smelter in Uganda and thus a high number of intermediaries. That’s why the copper is supplied to Nairobi, Kenya instead to get the price mentioned above.

[8] www.batteryrecycling.umicore.com

3 Results and Discussion

The results of the modelling are split up into 2 chapters: chapter 3.1 provides the results and detailed information of the baseline scenario, which serve as a reference for the sensitivity analyses in chapter 3.2.

Definitions	
Annual balance	= running costs + purchase costs + material revenues Balance of all revenues and expenses of the e-waste treatment business.
Running costs	All running costs of the business, not considering material revenue and purchase costs. This includes the costs of administration, collection, treatment, CMR, depreciation of investments and other costs.
Purchase costs	Covers the purchase of e-waste (from scavengers, households and via B2B).
Material revenue	The income and costs that are caused by supplying the processed material to downstream processing companies. Thereby the costs for the transport to those companies are included.

3.1 Baseline Scenario

As mentioned in chapter 2.2, the baseline scenario is the basis of comparison for the sensitivity analyses of different economically relevant parameters of the e-waste treatment business.

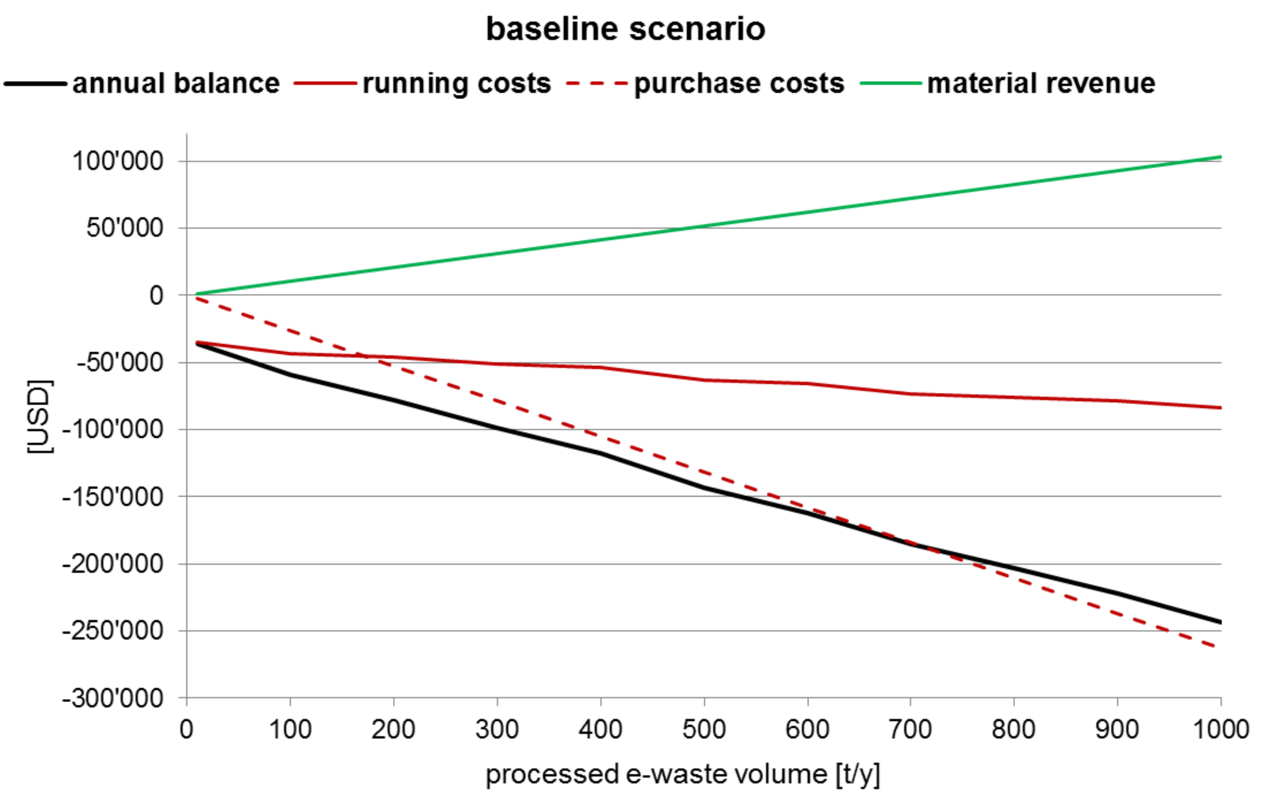

Figure 2. Model results for the baseline scenario; annual balance = running costs + purchase costs + material revenue.

Figure 2 demonstrates that the business is loss-making under the conditions of the baseline scenario. No break-even is reached. At an annual throughput of 1’000 t/y of e-waste, a deficit of almost -250’000 USD results. However, having a closer look at the purchase costs (= the expenses incurred for the collection/purchase of e-waste) reveals that these costs cause the largest share of the deficit. If these expenses were omitted, a positive annual balance would result as the material revenue (100’000 USD at 1’000 t/y) exceeds the running costs of the entire business (85’000 USD at 1’000 t/y).

The detailed listing of the material revenue and the purchase costs for each appliance shows that the **CRT TVs and CRT monitors** are a major cost driver (Table 5). To give an idea of the economic potential of each appliance, the generated material revenue and the incurred purchase costs of each are added up in the lower right corner of the table (note: the running costs of the business are not considered here).

Table 5. Detailed breakdown of processed volumes, material revenues and purchase costs for the appliances considered in the baseline scenario (1'000 t/y). On the lower right corner the material revenue and the purchase costs are added up.

	processed volume		material revenue		
	t/y	units/y	total USD	USD/kg	USD/unit
PC/ Server	200 t/y	21'053 units/y	303'310	1.52	14.41 /unit
Notebook	11 t/y	3'929 units/y	20'794	1.89	5.29 /unit
Printer/Scanner/Copier	50 t/y	11'111 units/y	7'633	0.15	0.69 /unit
IT accessoires	20 t/y	20'619 units/y	4'885	0.24	0.24 /unit
CRT monitor	300 t/y	17'647 units/y	-51'559	-0.17	-2.92 /unit
FPD monitor	10 t/y	2'000 units/y	5'599	0.56	2.80 /unit
CRT TV	390 t/y	10'000 units/y	-199'122	-0.51	-19.91 /unit
FPD TV	19 t/y	1'118 units/y	11'852	0.62	10.60 /unit
Total	**1'000.00 t/y**	**87'476 units/y**	**103'392**	**0.10**	**1.18**

	purchase costs			revenue + purchase	
	total USD	USD/kg	USD/unit	total USD	USD/unit
PC/ Server	-115'789	-0.58	-5.50 /unit	187'521	8.91 /unit
Notebook	-12'964	-1.18	-3.30 /unit	7'830	1.99 /unit
Printer/Scanner/Copier	-6'111	-0.12	-0.55 /unit	1'522	0.14 /unit
IT accessoires	-4'536	-0.23	-0.22 /unit	348	0.02 /unit
CRT monitor	-58'235	-0.19	-3.30 /unit	-109'795	-6.22 /unit
FPD monitor	-4'400	-0.44	-2.20 /unit	1'199	0.60 /unit
CRT TV	-55'000	-0.14	-5.50 /unit	-254'122	-25.41 /unit
FPD TV	-6'147	-0.32	-5.50 /unit	5'705	5.10 /unit
Total	**-263'183**	**-0.26**	**-3.01 /unit**	**-159'792**	**-1.83 /unit**

A further breakdown into the different materials supplied to downstream companies (Table 6 and Table 7) allows to identify the materials generating the highest income[9]:

[9] Here, income is distinguished from revenue. The material revenue encompasses the material income generated and the material costs caused by supplying the material to the downstream processing companies.

- **printed wiring boards, high grade** (46%, 215'000 USD at 1'000 t/y),
- processors (11%, 52'000 USD at 1'000 t/y))
- and iron[10] (9%, 42'000 USD at 1'000 t/y));

and causing the most costs, respectively:

- **CRT glass** (97%, -350'000 USD at 1'000 t/y).

Table 6. Share that each material contributes to the downstream processing income (transport costs included); per appliance and total income (baseline scenario). Materials that contribute >25% are shaded in grey.

% of income	PC/Server	Laptop	Printer/scanner/ copying machine	IT accessoires	CRT monitor	LCD monitor	CRT TV	LCD TV	Total
Aluminium	5.1%	2.7%	1.8%	0.0%	5.8%	2.3%	10.0%	7.5%	5.4%
Iron/ Steel	9.3%	0.6%	27.6%	11.7%	9.1%	14.1%	2.2%	14.9%	8.9%
Copper	3.1%	0.2%			23.3%				5.6%
Neodym magnet	0.3%	0.5%							0.2%
Bronze/Brass		0.3%							0.0%
Stainless Steel	0.1%	0.1%							0.1%
Plastics	0.4%	1.0%	21.8%	21.2%	5.8%	2.1%	11.9%	2.4%	2.8%
Cable with plugs		0.1%							0.0%
Cable w/o plugs	4.2%	4.8%	21.3%	48.8%	14.8%	5.2%	19.0%	3.1%	7.7%
Processors	15.6%	21.1%							11.2%
PWB, Q1	60.8%	67.1%				76.3%		71.9%	**46.1%**
PWB, Q2	0.5%	0.2%	23.3%	13.8%	20.2%		27.0%		6.0%
PWB, Q3	0.5%		2.2%	4.5%	5.2%		10.2%		2.0%
Motors/Ind./Trans.	0.1%	0.1%	2.0%		2.4%	0.1%	1.8%	0.3%	0.6%
Deflection coil					13.4%		17.6%		3.4%
Getterpill					0.1%		0.3%		0.0%
Batteries	0.0%	1.2%							0.1%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

The figures in Table 8 confirm that for the given e-waste composition in the baseline scenario, the economically most relevant appliances are the **PCs (income)** and the **CRT TVs and CRT monitors (costs)**.

[10] ferrous scrap

Table 7. Share that each material contributes to the downstream processing costs (transport costs included); per appliance and total costs (baseline scenario). Materials that contribute >25% are shaded in grey. Baseline scenario.

% of costs	PC/Server	Laptop	Printer/scanner/ copying machine	IT accessoires	CRT monitor	LCD monitor	CRT TV	LCD TV	Total
Mixed scrap	24.9%	22.6%	39.7%	100.0%	0.2%	6.2%	0.1%	4.4%	0.6%
Glass			6.7%			0.8%		0.3%	0.0%
Residual waste		0.1%	1.3%			0.2%		0.2%	0.0%
Batteries									
Capacitors	75.1%		11.9%		1.5%	3.8%	0.5%	3.0%	1.6%
LCD-displays		75.4%	9.6%			84.6%		76.5%	0.9%
Fluorescent tubes		1.9%	27.0%			4.3%		15.5%	0.2%
Printer Cartridges			3.7%						0.0%
CRT glass					98.3%		99.4%		**96.7%**
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 8. Share that each appliance contributes to the total downstream processing income and costs, respectively. Baseline scenario, at a total processed volume of 1'000 t/y. Appliances that contribute >25% are shaded in grey. Volume in t/y, income and costs in USD.

	PC/Server	Laptop	Printer/scanner/ copying machine	IT accessoires	CRT monitor	LCD monitor	CRT TV	LCD TV	Total
Processed volume	***200***	***11***	***50***	***20***	***300***	***10***	***390***	***19***	***1'000***
Total income	306'689	21'825	8'300	4'935	71'788	6'860	34'820	13'832	469'048
% of total income	65.4%	4.7%	1.8%	1.1%	15.3%	1.5%	7.4%	2.9%	100.0%
Total costs	-3'379	-1'031	-667	-50	-123'347	-1'261	-233'942	-1'980	-365'657
% of total costs	0.9%	0.3%	0.2%	0.01%	33.7%	0.3%	64.0%	0.5%	100.0%

Table 9. Required throughput to get together the exemplary "required minimal PWB lot size" of an integrated smelter (according to baseline scenario).

	Minimal lot size (Umicore)	**required throughput to reach the minimal lot size at different dismantling depths**		
PWB type		**C (baseline)**	B	A
high grade (Q1)	5 t	**220 t/y**	230 t/y	280 t/y
medium grade (Q2)	7 t	**610 t/y**	640 t/y	690 t/y
low grade (Q3)	10 t	**450 t/y**	6'300 t/y	- *(no PWB Q3)*

With regard to the material revenue a crucial parameter are the required **minimal lot sizes** for different materials. The figures in Table 9 show the exemplary conditions of the end-processor Umicore[11] in Belgium. Even though the PWBs are shipped to an intermediary in the baseline scenario, this aspect should always be taken into account for the financial planning as unsold valuable materials hamper the cash flow.

For the financial planning of the e-waste treatment facility, the investment costs have to be included, too. In the model, the investment costs cover the acquisition of the real estate, a building for offices and workspace, a truck and various equipment for administrative and dismantling staff. An increasing number of employees causes a rise in investment costs and vice versa. However, for the different scenarios applied in the sensitivity analysis the **investment costs do not vary significantly** (at the same e-waste throughput). At an annual e-waste throughput of 1'000 t/y, they range between 75'000 and 110'000 USD (baseline scenario: 95'000 USD, see Figure 3). The investment costs are thus not reproduced in the results for the sensitivity analyses. Instead an overview is given in Table 22 in the appendix.

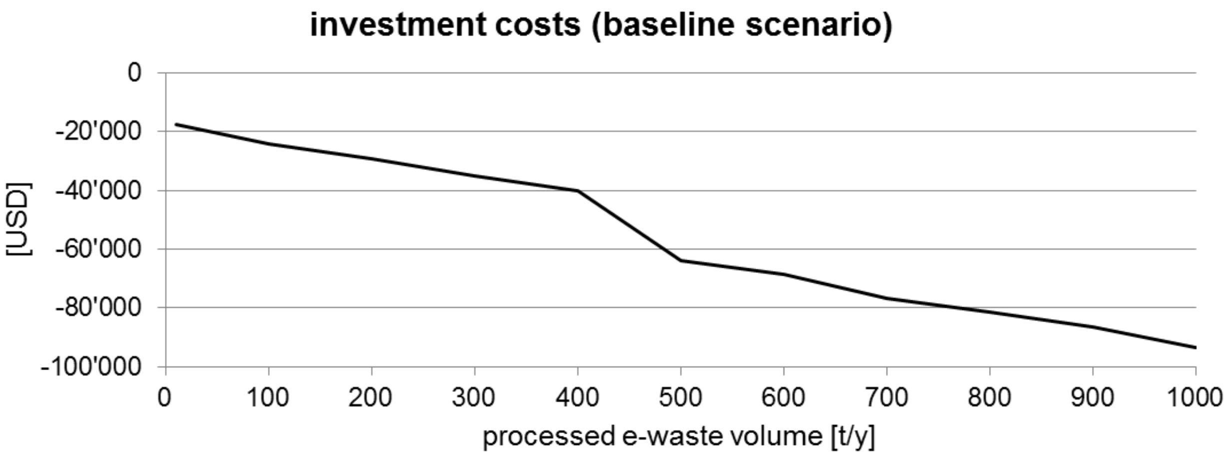

Figure 3. Model results for the baseline scenario; investment costs.

3.2 Sensitivity Analyses

To evaluate the economic relevance of the different parameters and processes of the e-waste treatment facility, simple sensitivity analyses are carried out. With different defined parameter sets (e.g. different commodity prices), the processed e-waste volume per year is varied (x-axis, in tons/year) in order to examine if the business performance increases or decreases (y-axis, in USD) with a rising treated volume. The different parameter sets and the respective results are described in the following chapters.

3.2.1 WEEE Composition

Each material has a certain positive or negative value on the market (see Table 19 in the appendix). Due to the differing material composition of the appliances (see Table 17 and Table 18 in the appendix), the overall appliance composition of the processed e-waste has a direct impact

[11] http://umicore.com/en/

on the business performance. Three different scenario sets regarding the composition of the (W)EEE bulk are presented below.

The **first scenario set** describes the impact of collecting and treating a (W)EEE bulk consisting of IT equipment (IT), of TV sets (TV) and all appliances considered in the model (all appliances). The details of the scenarios are listed in Table 10. In Figure 4 it becomes apparent that the treatment of IT devices performs significantly better than the treatment of TV devices. Despite the high share of the cost-intensive CRT monitors (51%), the IT scenario reaches break-even at a processed volume of 400 t/y and yields a profit of 50'000 USD at 1'000 t/y. On the contrary, the TV scenario results in a deficit of -660'000 USD at 1'000 t/y, which is significantly worse than the baseline scenario (-250'000 USD, black line). This is a consequence of the heavy CRT TVs, which contain a 75% share of CRT glass on average, and the absence of a large material stream generating income. If all further appliances are treated as well (baseline + kettles, irons, mobile phones, audio and video appliances), the economic performance slightly deviates from the baseline scenario (-200'000 USD at 1'000 t/y). With their large share in the appliance composition and their high positive (PCs) and negative (CRT-monitors and -TVs) value, those appliances determine the financial performance to a large extent.

Table 10. Applied scenarios for the WEEE composition (in weight-%), first scenario set. For details on the processed number of appliances see Table 23.

Appliance	baseline	IT	TV	all appliances
Kettle				3.0%
Iron				3.0%
PC/ Server	20.00%	33.8%		16.7%
Notebook	1.10%	1.9%		0.9%
Printer	5.00%	8.5%		4.2%
IT accessoires	2.00%	3.4%		1.7%
Mobile phone				0.5%
CRT monitor	30.00%	50.8%		25.1%
LCD monitor	1.00%	1.7%		0.8%
Audio appl.				5.0%
Video appl.				5.0%
CRT TV	39.00%		95.4%	32.6%
LCD TV	1.90%		4.6%	1.6%

It should be taken into account that the number of processed units per year in the three scenarios differs for the same processed volume (tons/year). This difference is a consequence of the average weight of all the appliances considered in a scenario that varies along with the alteration of the appliance composition (for details on the processed number of appliances see Table 24). When comparing the scenarios, the absolute levels of the annual balances thus have to be interpreted with due care. However, the tendencies for the annual balances are correct.

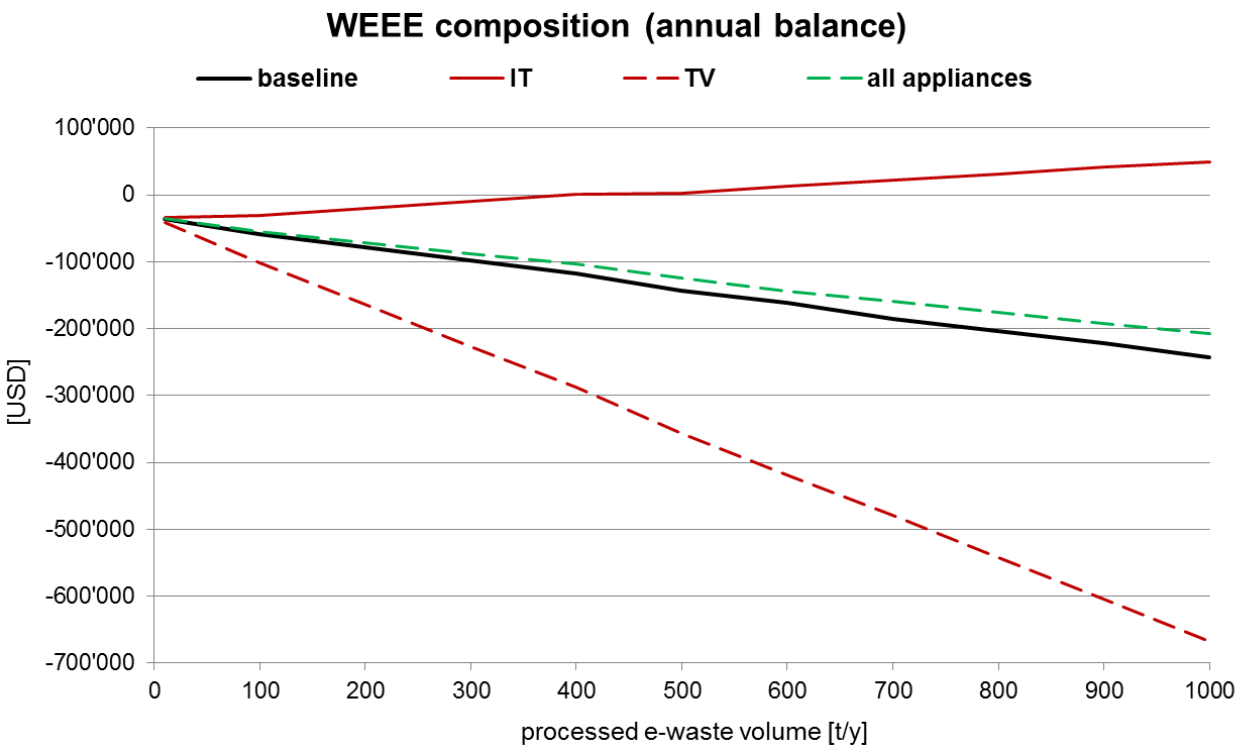

Figure 4. Sensitivity of business performance (annual balance) to a varying WEEE composition. First scenario set.

The two further scenario sets concern the economic impact of the CRTs and of the tendency towards LCD technology. For both analyses, the issue described above is taken into account by comparing the same number of units.

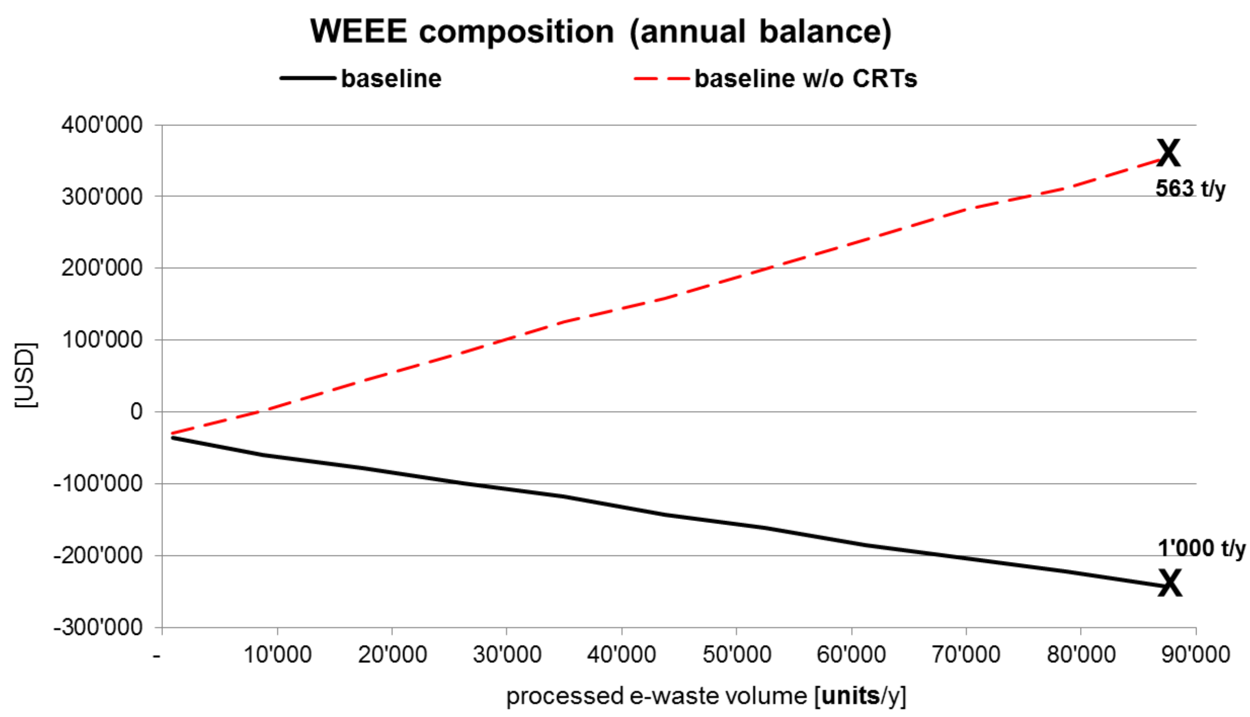

Figure 5. Comparison of the annual balance for the baseline scenario with and without CRTs (in units/y[12]). Second scenario set.

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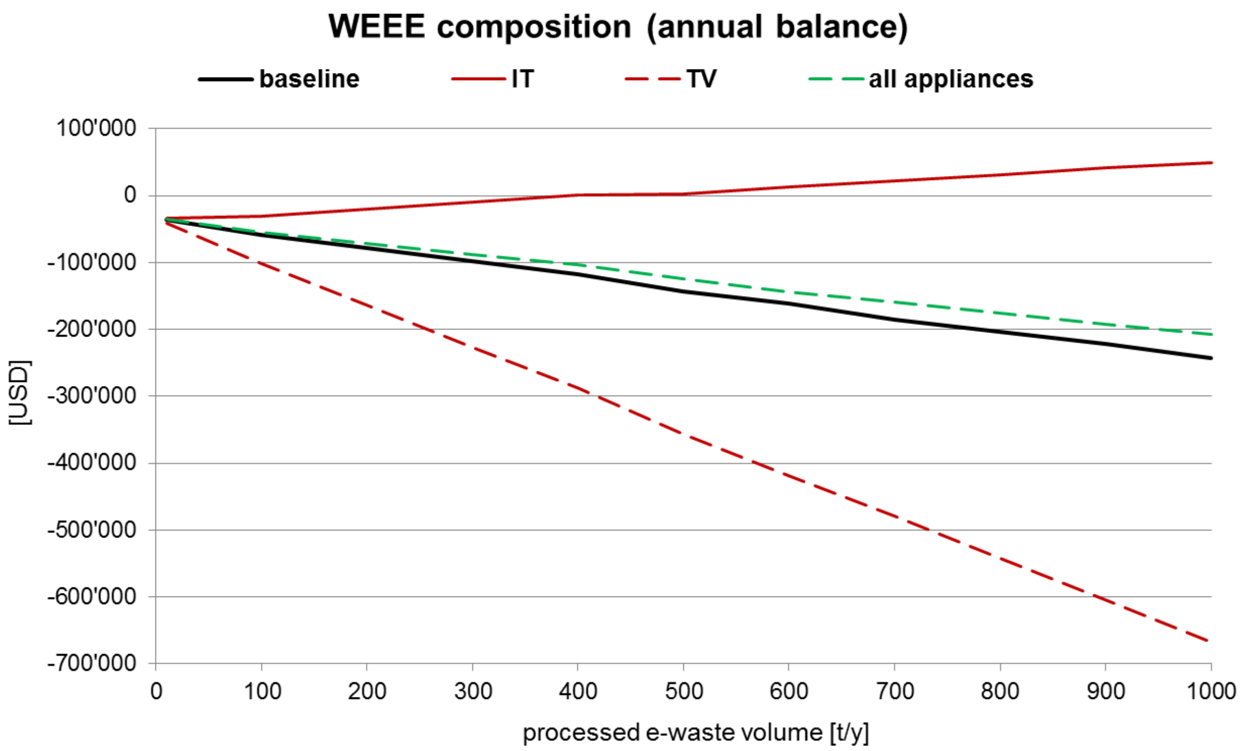
[12] The x-axis shows the processed volumes in units/y (instead of tons/y). Due to the differing average weights of the appliances a differing number of appliances would result at the same processed amount by weight. This circumstance would affect the economic performance (as it is the case for Figure 4



).

In the **second scenario set** the baseline scenario (10% LCD / 90% CRT) is compared to a scenario with the same appliance composition except the TVs and monitors, which are assumed to be 100% LCDs instead of 10% LCD / 90% CRT. In Figure 5 the significant effect of a scenario without CRTs is demonstrated: in the scenario *baseline w/o CRTs* the breakeven is attained when ca. 9'000 units/y are processed (ca. 60 t/y). At 563 t/y of treated e-waste, which corresponds to the same number of treated units as the 1'000 t/y in the baseline scenario, a profit of 350'000 USD is yielded (**Δ** annual balance: 600'000 USD).

With regard to obsolete TVs and PC monitors, it will still take several years until the LCD share is greater than the CRT share. The treatment of CRT glass will thus remain a technical and financial challenge for e-waste treatment businesses in a short and medium term. But the evident tendency towards the LCD technology will gradually reduce the burden of the CRT monitors in the e-waste business.

In the scenarios of the **third scenario set** the treatment of (only) PCs with a differing share of LCD vs. CRT monitors is simulated (see Table 11). As expected, the results in Figure 6 confirm the great financial burden of the CRT monitors. The larger their share, the poorer the economic performance of the e-waste business. But even with a 100% share of CRT monitors a positive tendency in the annual balance results. The figures in Table 12, which show the material revenue for the PC (tower), the CRT and the LCD monitors (excl. the further running costs), reveal that the great revenue of the PC towers compensates the costs for the adequate treatment of the CRT monitors.

Table 11. Scenario definition for the comparison of CRT- vs. LCD-PCs (PC tower + monitor). Third scenario set.

	CRT mon.	**LCD mon.**	**PC (tower)**
	% (units)	***% (units)***	***% (units)***
10% LCD / 90% CRT	90%	10%	100%
50% LCD / 50% CRT	50%	50%	100%
100% LCD		100%	100%
100 % CRT	100%		100%

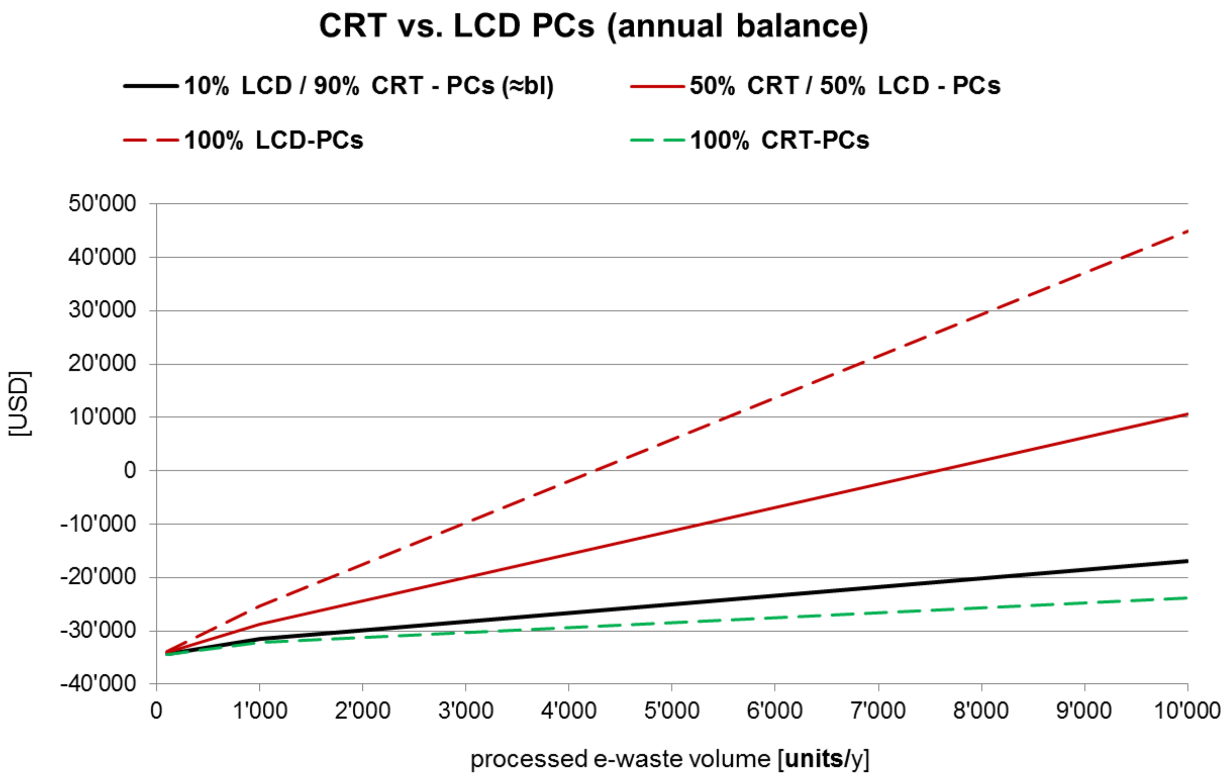


Figure 6. Comparison of the annual balance for treatment of PCs with a varying share of LCD and CRT monitors, respectively (in units/y). Third scenario set.

Table 12. Comparison of the material revenues generated by the treatment of 10'000 PC units (= 10'000 PCs + 10'000 monitors) with different predefined CRT / LCD shares. The scenario *10% LCD / 90% CRT* represents the share given in the baseline scenario. The further running costs are not considered. Third scenario set.

	volume		material revenue (transport costs included)		
	units/year	tons/year	LCD mon. (USD)	CRT mon. (USD)	PCs (USD)
10% LCD / 90% CRT	**10'000**	252	2'800	-26'295	144'072
50% LCD / 50% CRT	**10'000**	205	13'998	-14'608	144'072
100% LCD	**10'000**	145	27'996	-	144'072
100% CRT	**10'000**	265	-	-29'217	144'072

3.2.2 Collection

According to experiences made by Empa in various countries, e-waste collection is both a decisive and difficult process for an e-waste treatment business. To account for this circumstance, different purchase prices and collection strategies are factored in for the sensitivity analysis.

In many lower income countries, the **purchase price** offered for e-waste is an important incentive for scavengers, households as well as companies and institutions to deliver their appliances to an e-waste treatment business. As it is not possible to estimate a precise purchase price (see chapter 2.2), this parameter is varied by a large range in the analysis. The purchase price applied in the baseline scenario was multiplied by the factors 0.25, 0.5, 2, 4 and 0 (Table 13).

The results in Figure 7 show the significant impact of a varying purchase price on the annual balance of the business. This is not surprising given the high relevance of the purchase costs in the budget of the business in the baseline scenario (see Figure 2 in chapter 3.1; the purchase costs outweigh the material revenue by a factor 2.5). In case the appliances are provided for free, the annual balance reaches moderately positive levels at 1'000 t/y (20'000 USD). However, even at the lowest remuneration (factor 0.25) the annual balance is decreasing slowly but steadily with rising e-waste volumes (-45'000 USD at 1'000 t/y). In the scenarios *factor 0.5, 1, 2 and 4* the total purchase costs almost equal the annual balance (compare with Figure 8). In scenario factor 4 the annual balance reaches a deficit of -1 million USD.

Table 13. Purchase prices paid to the informal sector (IS) and to companies & authorities (B2B) for the different scenarios applied (in USD/unit).

in USD/unit	baseline (1)		factor 0.25		factor 0.5		factor 2		factor 4	
	IS	B2B	IS	B2B	IS	B2B	IS	B2B	IS	B2B
Kettle	**-0.20**	**-0.24**	-0.05	-0.06	-0.10	-0.12	-0.40	-0.48	-0.80	-0.96
Iron	**-0.20**	**-0.24**	-0.05	-0.06	-0.10	-0.12	-0.40	-0.48	-0.80	-0.96
PC/ Server	**-5.00**	**-6.00**	-1.25	-1.50	-2.50	-3.00	-10.00	-12.00	-20.00	-24.00
Notebook	**-3.00**	**-3.60**	-0.75	-0.90	-1.50	-1.80	-6.00	-7.20	-12.00	-14.40
Printer	**-0.50**	**-0.60**	-0.13	-0.15	-0.25	-0.30	-1.00	-1.20	-2.00	-2.40
IT accessoires	**-0.20**	**-0.24**	-0.05	-0.06	-0.10	-0.12	-0.40	-0.48	-0.80	-0.96
Mobile phone	**-0.80**	**-0.96**	-0.20	-0.24	-0.40	-0.48	-1.60	-1.92	-3.20	-3.84
CRT monitor	**-3.00**	**-3.60**	-0.75	-0.90	-1.50	-1.80	-6.00	-7.20	-12.00	-14.40
LCD monitor	**-2.00**	**-2.40**	-0.50	-0.60	-1.00	-1.20	-4.00	-4.80	-8.00	-9.60
Audio appl.	**-0.50**	**-0.60**	-0.13	-0.15	-0.25	-0.30	-1.00	-1.20	-2.00	-2.40
Video appl.	**-0.50**	**-0.60**	-0.13	-0.15	-0.25	-0.30	-1.00	-1.20	-2.00	-2.40
CRT TV	**-5.00**	**-6.00**	-1.25	-1.50	-2.50	-3.00	-10.00	-12.00	-20.00	-24.00
LCD TV	**-5.00**	**-6.00**	-1.25	-1.50	-2.50	-3.00	-10.00	-12.00	-20.00	-24.00

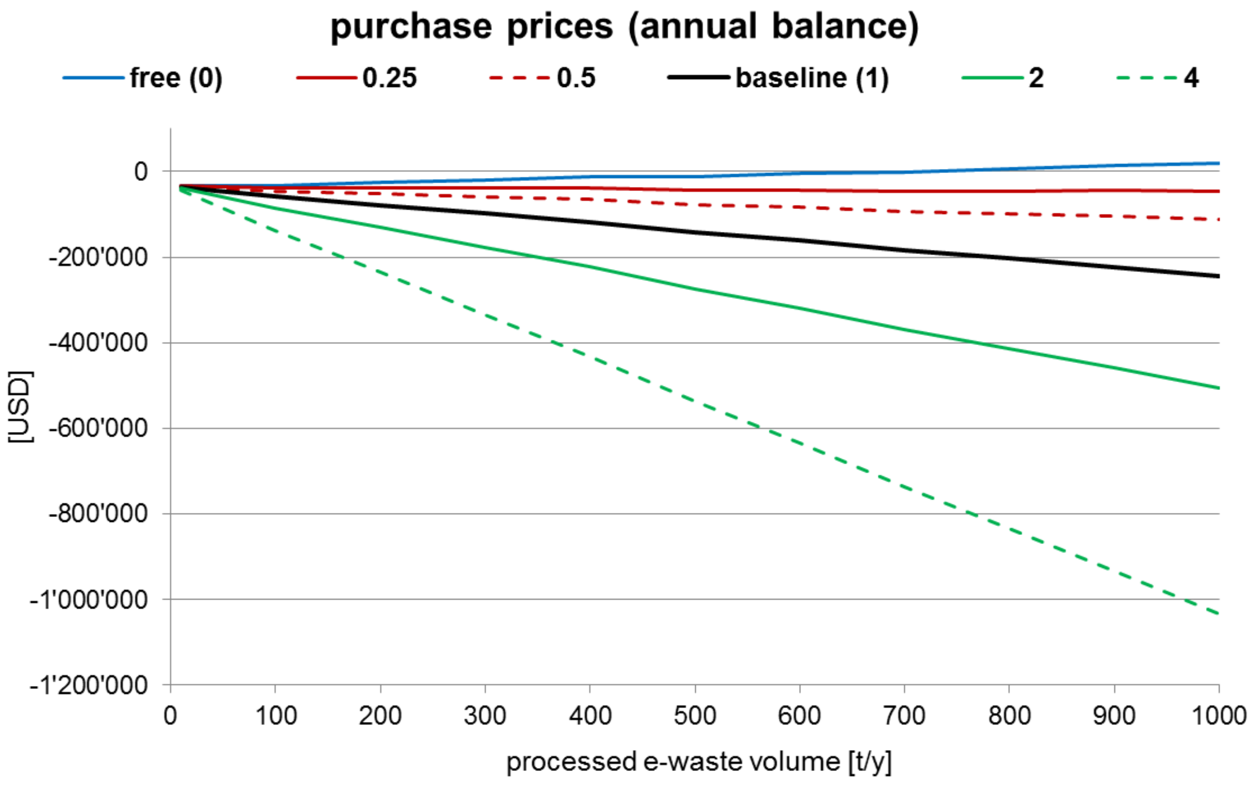


Figure 7. Sensitivity of the business performance (annual balance) to the purchase price for e-waste (i.e.: 0.25 = baseline p. prices x 0.25).

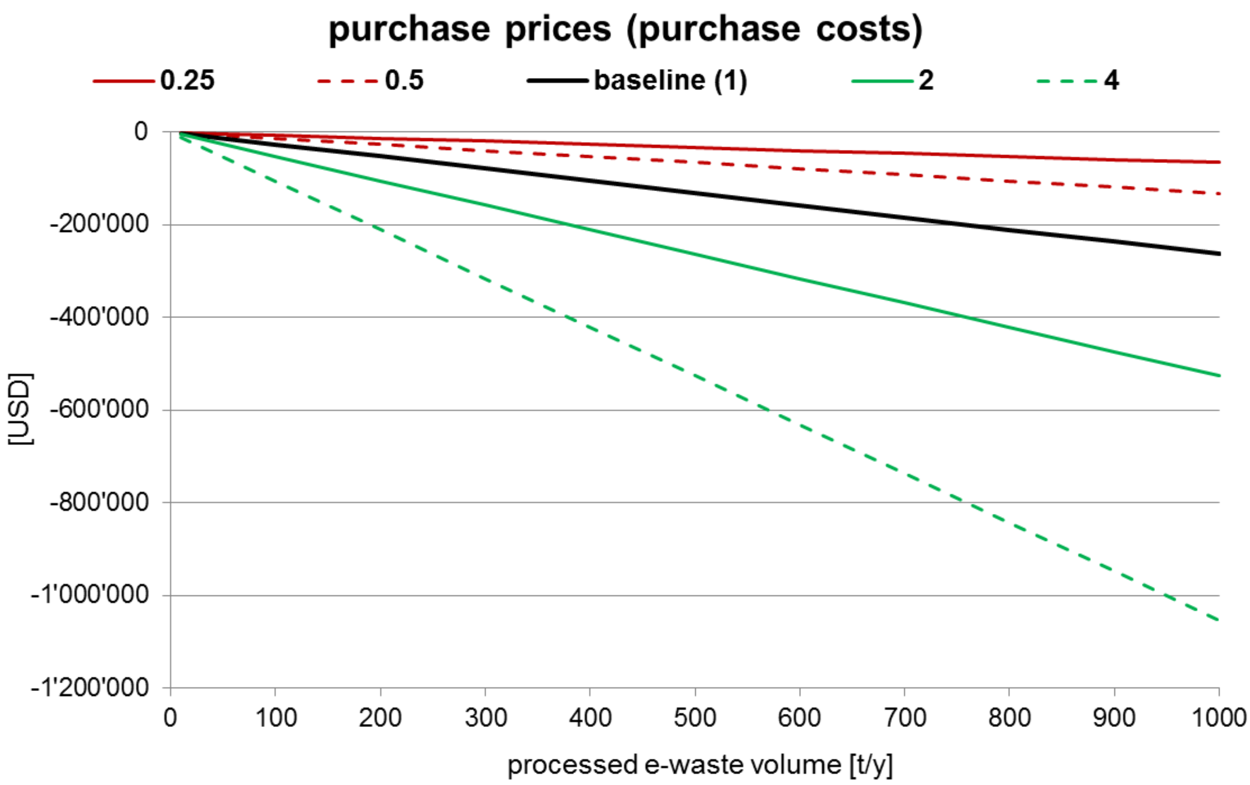


Figure 8. Total purchase costs for e-waste for different purchase price scenarios.

Although those figures seem exaggerated, not even the purchase prices in scenario *factor 4* exceed the prices gathered in a biased field survey by the UCPC in Kampala (see Table 21 in the appendix). Given the great relevance of the purchase costs in the annual balance, it is strongly advised to find solutions to get the appliances donated or at low purchase prices. However, to get together a sufficient amount of e-waste the effect of a high incentive should not be neglected.

Contrary to the purchase costs, the further costs caused by different **collection schemes** do not have a significant impact on the annual balance, as the results in Figure 9 demonstrate. With a collection at the facility (*100% in-house collection*), the best annual balance results (-220’000 USD at 1’000 t/y). The difference to the scenarios *100% B2B* and 50*% collection points / 50% B2B* is 50’000 USD at a processed volume of 1’000 t/y. This difference is due to the additional staff and infrastructure required for the collection points and the higher purchase price applied in the B2B scheme (120%), respectively.

Concerning the issue of the collection costs it is important to take into account that the model does not consider the costs for public relation campaigns (i.e. awareness raising and sensitization).

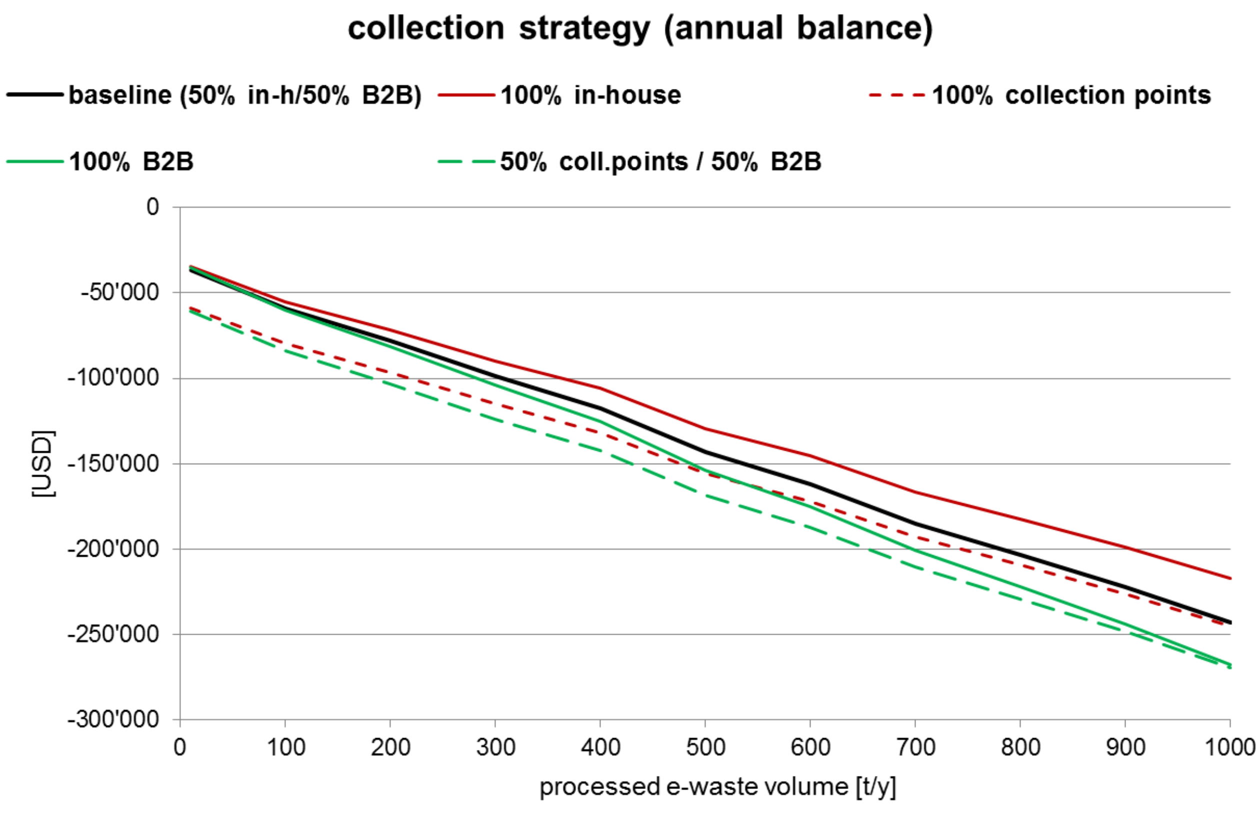


Figure 9. Sensitivity of business performance (annual balance) to different collection strategies.

3.2.3 Dismantling

For the key process dismantling two parameters are analysed that are interrelated: the dismantling depth and the wages for the dismantling staff.

The **dismantling depth** describes how well the materials of the appliances are segregated. The more time is invested per appliance, the better the materials (e.g. contaminated and valuable materials) can be separated, i.e. the deeper the dismantling. A deeper dismantling depth implicates two effects, that oppose each other financially: (1) more dismantling staff has to be employed (more costs) and (2) the value of the materials is rising (more revenue) and the volume of cost-intensive materials is decreasing (less costs), respectively. With the solid data basis provided in the model, the analysis of the dismantling depth scenarios enables to analyse which of the effects is stronger[13]. The details on the dismantling times and material output of the three dismantling depth are found in Table 17 and Table 18 in the appendix.

The results in Figure 10 reveal that the deeper the dismantling is, the better the economic performance of the business. In case of a superficial dismantling (A), the business presents a deficit of -440’000 USD at a treated volume of 1’000 t/y, whereas the deep dismantling depth of the baseline scenario (C, black line) results in a deficit of “only” -250’000 USD at the same processed volume.

These results suggest that the gained material value of a deeper dismantling significantly exceeds the greater expenses for more dismantling workers.

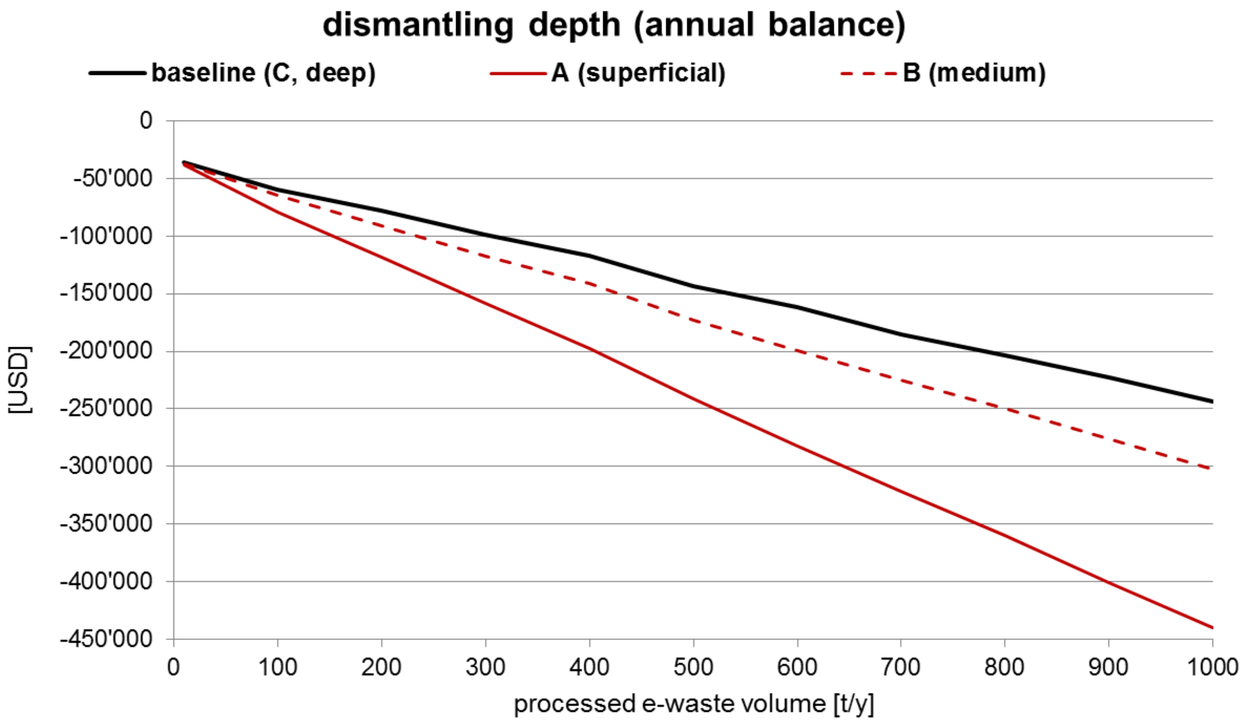


Figure 10. Sensitivity of business performance (annual balance) for different dismantling depths.

[13] A detailed analysis of the optimal dismantling depth for computers from an economic and environmental perspective can be found in Gmuender (2007).

To get an idea about the financial impact of the **wages**, the wages which are applied in the baseline scenario for the dismantling staff are decreased and increased by 25%[14] (see Table 14), respectively.

Table 14. Scenarios for the variation of the wages (in USD/month).

	baseline	factor 0.75	factor 1.25
Unskilled worker	120 USD	90 USD	150 USD
Skilled worker	140 USD	105 USD	175 USD

The results in Figure 11 demonstrate the insignificant effect of the wages on the business performance. Between the high wage scenario (-250'000 USD) and the low wage scenario (-235'000 USD), the difference of the annual balance only amounts to 15'000 USD. A slight rise in the wages can thus be considered as not relevant for the business. But at the same time it has to be considered that a fair wage can attract skilled and motivated staff, a fact that might have a very positive effect for the business.

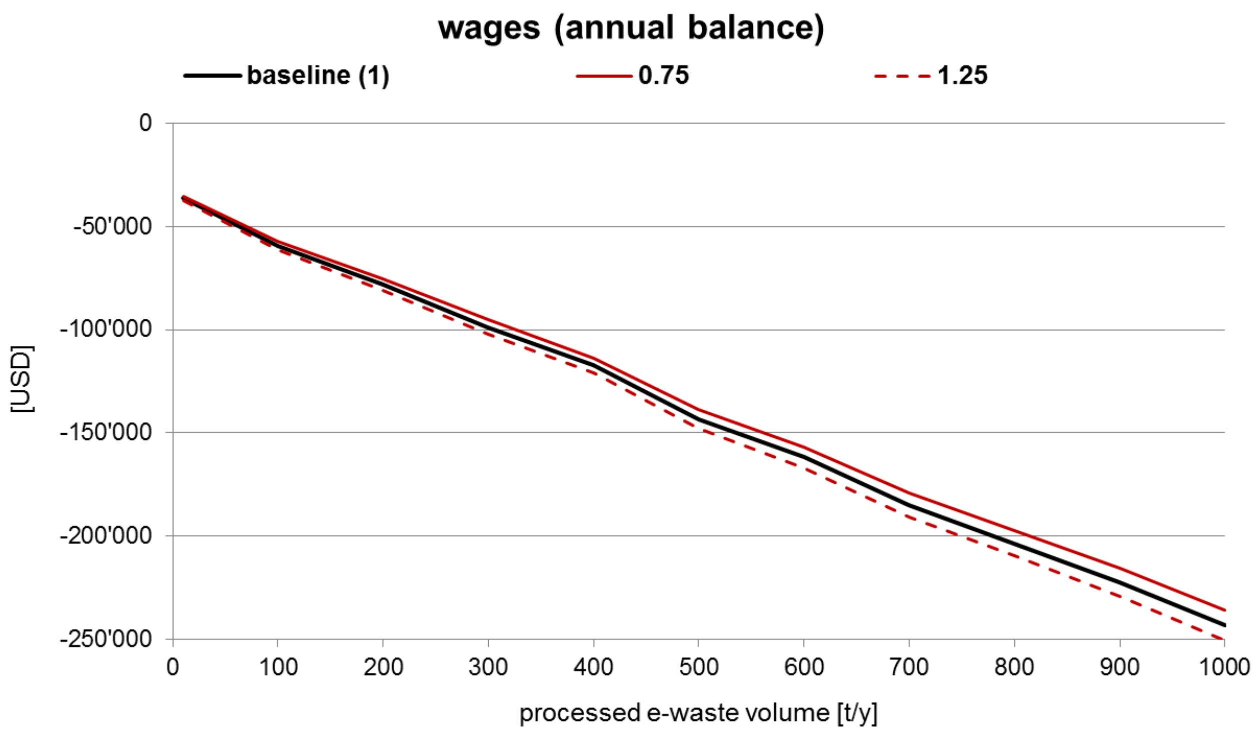


Figure 11. Sensitivity of business performance to the wage of the dismantling staff (see Table 16).

[14] As the wages in the baseline scenario are realistic and quite fair, only a relatively small variation of wages has been applied in the sensitivity analyses (+/- 25% of the original wage).

3.2.4 Downstream Processing

For the analyses with regard to the downstream processing, the commodity prices and the downstream destinations are altered. Additionally, for the analysis of the commodity prices a scenario without transport costs is assessed.

A significant share of the material revenues is linked with the sale of metals or PWBs (see Table 6), whose prices are dependent on **commodity prices** set on the global market. To analyse the impact of varying commodity prices on the business performance and to assess the vulnerability of the business to sharp drops in commodity prices, several commodity price scenarios are applied in the model. A data series of the commodity prices between 2002 – 2012 (averaged per calendar year, converted into USD of the year 2012) provides the basis for the scenarios. The commodity prices of silver (Ag), aluminium (Al), gold (Au), cobalt (Co), copper (Cu), iron (Fe), neodymium (Nd) oxide, nickel (Ni) and palladium (Pd) are considered in the model. For different materials a commodity price dependence is estimated based on the material composition and experiences made by Empa and D.R.Z. The complete data series of the commodity prices (Table 15) and the estimated dependences (Table 16) are found in the appendix.

As depicted in Figure 12 the business performance changes significantly as a result of varying commodity prices. In no scenario the annual balance reaches the breakeven, with scenario *2011* performing best (-210’000 USD at 1’000 t/y). The comparison of the business performances of *2002* (-610’000 USD) and *2012* (baseline, -250’000 USD) demonstrates the great significance of this parameter. The strong variation of the performances between *2009* and *2011* (**Δ** annual balance at 1’000 t/y: 220’000 USD) shows that the business conditions can change in a relatively short period of time, too. The recent drops in commodity prices confirm this risk (April – July 2013).

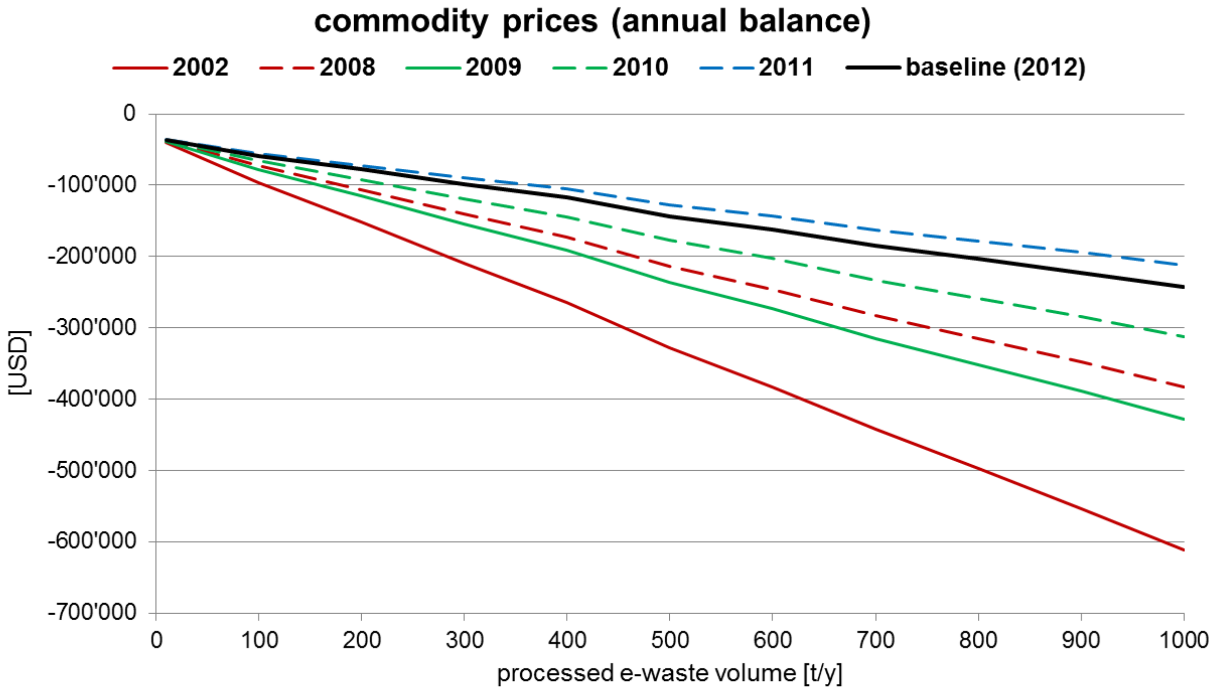


Figure 12. Sensitivity of business performance (annual balance) to varying commodity prices.

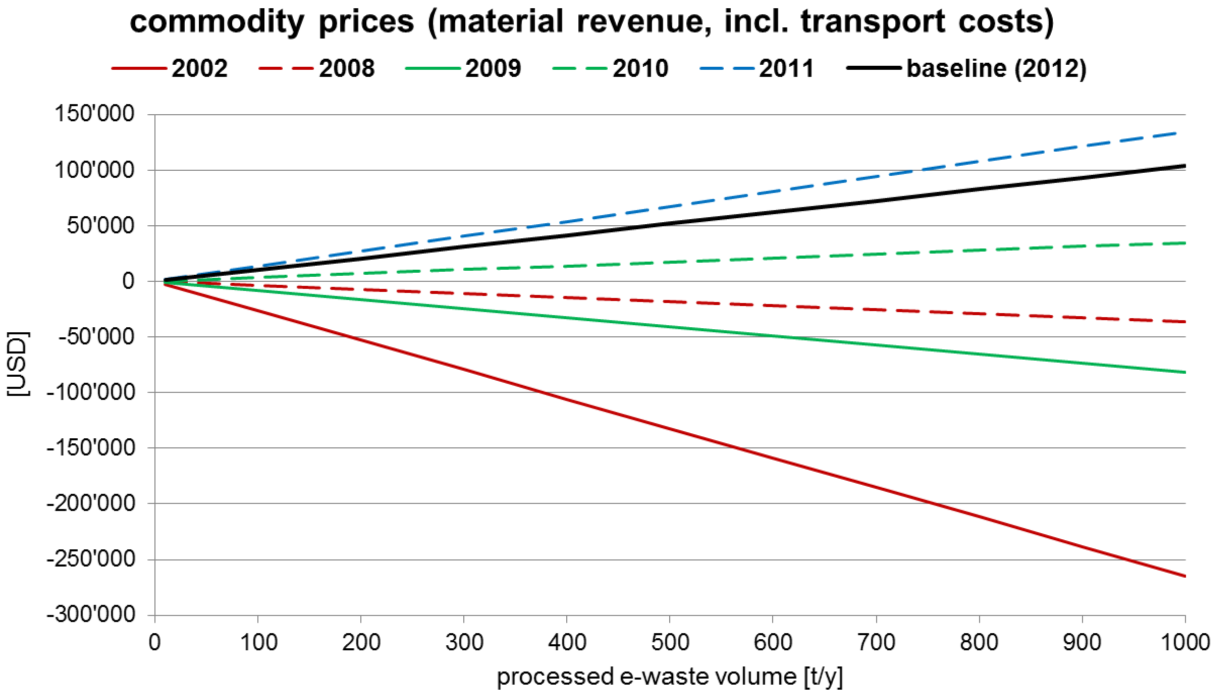


Figure 13. Sensitivity of the material revenues to varying commodity prices. The transport costs are taken into consideration in the material revenue.

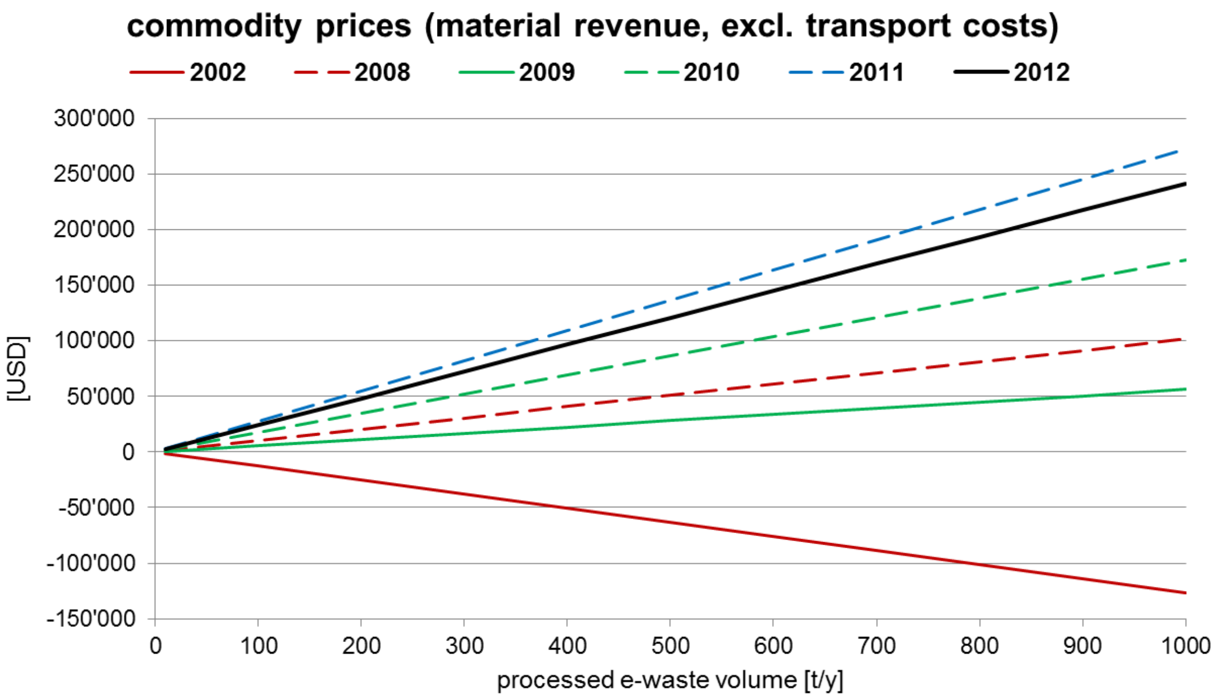


Figure 14. Sensitivity of the material income & costs to varying commodity prices. The transport costs are excluded in this figure.

Figure 13 focuses solely on the material revenue[15] of the business in order to stress the fact that under certain commodity price conditions (*2002*, *2008*, *2009*) the overall material revenue is negative. This prevents the business from becoming profitable on the basis of the intrinsic value of the e-waste.

This is partially a consequence of the high **transport costs**, too. Figure 14 shows the material revenue if the transport costs are set 0. When comparing Figure 13 and Figure 14, the adverse effect of the rocky transport situation in Uganda becomes apparent: due to the relatively high transport costs for regional and intercontinental destinations, the material revenue is reduced significantly and in some scenarios it even turns negative (*2008*, *2009*). In all scenarios the transport costs amount to 140'000 USD at 1'000 t/y. For details on the transport costs see Table 20 in the appendix.

According to various factors like processed volumes, transport conditions, preferences for certain cooperations/markets, etc., different **downstream destinations** are chosen for the material output of an e-waste treatment facility. As mentioned in chapter 2.2, in the baseline scenario it is sought to commercialize the materials on the local markets and in regional hubs wherever possible. To supply the "simple" materials (i.e. aluminium, ferrous scrap, wood, glass, possibly plastic) to the local markets is sound for two reasons: promote the local economy and reduce transport costs. For an initial phase of a business, it is certainly reasonable to cooperate with regional hubs, too, given that the processed volumes are likely to be small. This hampers both to do business at all and to negotiate with large companies, e.g. the integrated metal smelters.

In a second scenario (*Y*), the materials which – for reasons of adequate treatment – end up in enterprises of industrialised countries anyway (i.e. PWBs, batteries, CRT glass, LCD modules), are supplied directly to those companies without the involvement of any intermediaries.

Despite the greater transport costs, the business in scenario *Y* performs significantly better than in the baseline scenario *X* (*Y*: -80'000 USD and *X*: -250'000 USD at 1'000 t/y). With a sufficient material output, there is thus great potential in a direct supply to the end-processing companies. However, it is crucial to thoroughly clarify transport and customs issues (i.e. costs, delays) when considering a direct downstream supply.

[15] material revenue = material income + material costs (transport costs to downstream processing companies included)

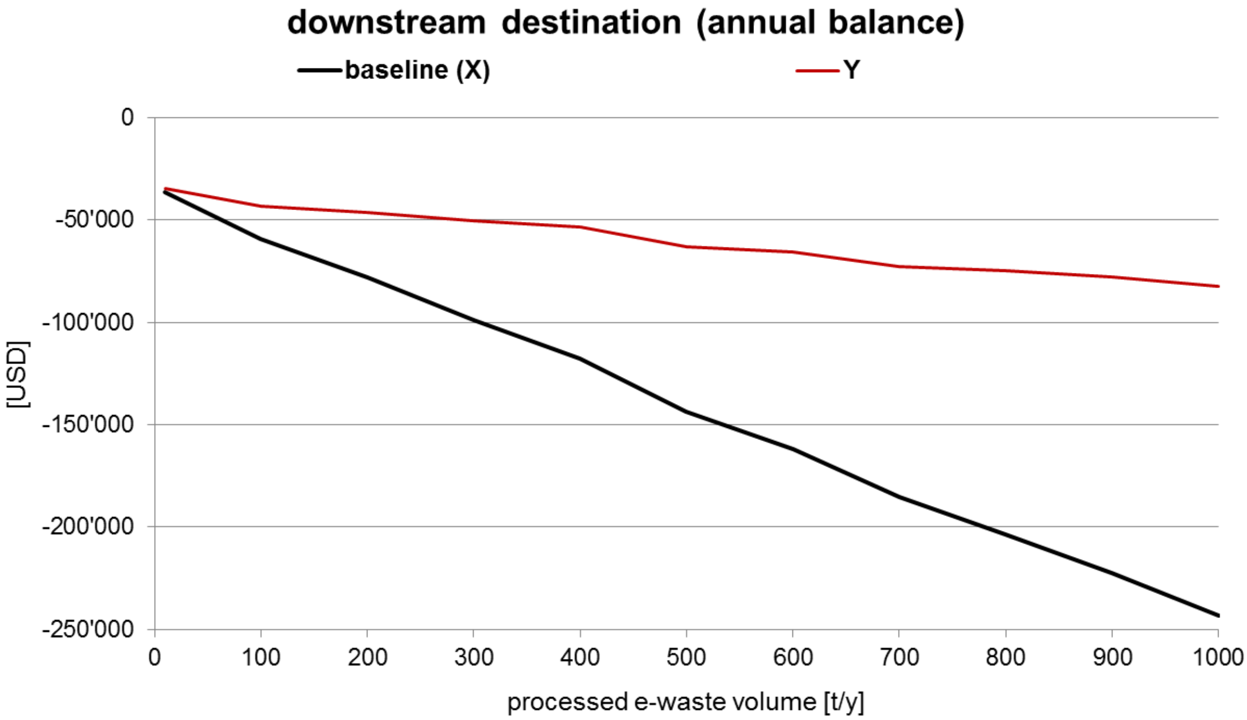


Figure 15. Sensitivity of business performance (annual balance) to different downstream scenarios (for details on the scenarios see Table 19 in the appendix).

4 Conclusions

Results of the financial modelling suggest that under the current local and global economic conditions the e-waste treatment facility in Kampala cannot achieve an economically self-sufficient business if solely relying on the intrinsic value of the treated material. In the baseline scenario, the business doesn't break even, also not if higher collection rates are achieved. In contrary, at a throughput of 1'000 t/y a deficit of -250'000 USD is made and every increase in the collection rate leads to an increase in the deficit. This is mainly due to two cost factors, which stand out from the others with regard to their significance: the **purchase prices for e-waste** that are paid to incentivize collection and **the costs for the treatment of cathode ray tubes (CRTs)**. In case the business could access further income streams to cover the high purchase costs of waste material or the CRT treatment costs, respectively, the business could be profitable. However, further factors like WEEE composition, commodity prices, dismantling depth and downstream destinations have a significant impact on the business performance, too.

Success and sustainability of such an e-waste treatment business thus depend on a multitude of parameters, which entail both opportunities and threats. Some crucial parameters have been analysed. The main conclusions of this sensitivity analysis are summarized below:

- The **composition** of the collected e-waste significantly affects the business performance. Admittedly, the composition of the effectively collected e-waste is difficult to predict and can only be partially influenced. For the financial planning of the initial operation of the facility it is certainly useful to consult experiences made in the region (WEEE composition) and to adapt the collection strategy accordingly.
- The **treatment of CRT glass** deserves special attention as it is the major cost driver for the business. In spite of the decreasing sales numbers of CRT monitors and CRT-TVs, they will still constitute a large proportion of the obsolete monitors in the medium term. Thus, further (regional) downstream processing alternatives which help to reduce costs along with the compliance of environmental standards should be analysed. In doing so, cooperation with lead smelters could be a potential alternative (see also Schluep et al. (2009)). However, a financial mechanism that copes with the costs of the CRT treatment is essential for the business. Thereby, it is important that this mechanism doesn't adversely affect the collection rate of CRTs. It's up to the local stakeholders to define whether this mechanism solely focuses on CRTs or if it covers all collected appliances.
- A key parameter for the economic performance of the business is the **purchase price** for e-waste: it should be low enough to prevent the business from running in (great) deficit and high enough to sufficiently stimulate collection. The few patchy data gathered in Uganda suggest a price for (W)EEE that is rather in the vicinity of the upper end of the calculated scenarios, a circumstance which – if true – would entail significant costs. Hence, a carefully and cleverly designed price system is required. The field survey revealed a certain willingness to donate e-waste (B2B).

- Economy of scale: to optimize internal processes and downstream processing channels (i.e. transportation, price negotiations, minimal lot sizes) it is favourable to attain sufficient **volumes** soon after the onset of operation.
- A **deep dismantling** of the appliances is not solely reasonable from an environmental and social point of view, but also from an economic perspective.
- Even with a deep dismantling, a variation in the **wages** of the dismantling staff does not significantly affect the economic performance. Additional to social motivation, the stimulus for skilled and motivated staff to work at the facility suggests to provide fair conditions of employment, incl. an attractive salary.
- **Commodity prices** have a significant impact on the business performance. As the recent drops in prices demonstrate (2013), this dependency has to be interpreted as a relevant risk for the business' profitability. A potential financing mechanism should be able to cope with such short-term volatility on the global markets.
- A further aspect to be considered are the required **minimal lot sizes** of PWBs and further materials. According to the baseline scenario, a minimal throughput between 220 and 610 t/y is necessary to get together the minimal lot sizes of the various PWB grades. As PWBs are a major revenue driver, unsold PWBs substantially hamper the cash-flow of the business. A strategy to avoid long-term interruption of revenues is to cooperate with similar projects at a regional level and uniting PWBs of several recycling facilities in a regional hub (as applied in the baseline scenario), which should allow to reach the critical volumes in a shorter time frame. Since a regional cross-frontier solution could raise strong resistance from the authorities, there is need for coordination and awareness building on a regional policy level.
- As Uganda is a landlocked country, the **transport** of goods to high-tech facilities in industrialised countries is time- and cost-intensive as well as riddled with bureaucratic obstacles. Therefore it's worth to thoroughly evaluate the different transport options[16] and to establish conditions that ease possible customs impediments. Furthermore it is likely that investments in equipment that help minimize the volume of the shipped goods pay off (i.e. crusher, shredder).

The current setting doesn't enable sustainably self-sufficient e-waste treatment business in Uganda. Hence, in order to enable a sustainable operation an additional income stream is required. It is therefore concluded that a sustainable e-waste treatment business can only grow in Uganda in combination with a comprehensive framework, which ensures:

1. that business sustainability is guaranteed under both favourable and unfavourable economic conditions. I.e. an additional flexible income stream enabled through a financing scheme needs to be established for periods in which the intrinsic value of the treated material is not sufficient for a break-even. Additionally, a seed-funding or providing grants in the initial phase of building up a business might be required;

[16] I.e. an option which seems to be working is the transport of goods from Nairobi to Mombasa by train. Apparently, costs are lower and the transport is more efficient than transport by road.

2. that e-waste businesses can grow in a level playing field. I.e. that rules set by legislation and standards, as well as monitoring and control mechanisms favour high standard operations;
3. that market incentives are set such as high collection and treatment rates are encouraged. I.e. appropriate collection processes need to be attracted, ensuring that high volumes of both valuable and non-valuable waste materials are collected equally and that those materials reach appropriate treating facilities.
4. that regional cross-national cooperation models are supported in order to gather critical volumes of e.g. PWBs. I.e. these models should allow e-waste businesses to participate on the global market for a maximal return of value for secondary raw materials, which also requires that government bodies guarantee a smooth, reliable and timely handling of export licenses and other administrative procedures to facilitate exports of certain e-waste materials.

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Glossary

Annual Balance = running costs + purchase costs + material revenues. Balance of all revenues and expenses of the e-waste treatment business.

Appliance Composition Appliance composition refers to the share each appliance has in the e-waste stream. It does not refer to the specific material composition of the appliances, see *Material Composition*.

Collection Collection comprises all the processes and infrastructure necessary to carry together the appliances, excluding the actions undertaken to spread information and raise the awareness among the society (see *Public Relations*).

CPU In this study, CPU (Central Processing Unit) refers to the computer tower. It does not include the monitor, except for special cases when the monitor and the CPU are enclosed in the same casing.

Dismantling Dismantling comprises any action undertaken to disassemble appliances in order to recycle/refine its components and materials. If not specified otherwise, in this study the term generally refers to manual dismantling.

Disposal Disposal comprises the landfilling of waste materials in (sanitary) landfills and the incineration of waste in adequate plants.

Downstream processes The downstream processes refer to the stages subsequent to the dismantling and comprise all recipients of any material, including the wholesalers and the stakeholders of the end-processing and the disposal.

End-processing The end-processing is part of the downstream processes and comprises the processes that aim for a material recovery, e.g. metals refining.

Informal Sector "The informal sector […] is the part of an economy that is not taxed, monitored by any form of government or included in any gross national product (GNP), unlike the formal economy." (Wikipedia 2011) Examples are scavengers or non-registered companies.

Investment costs In the model, those costs cover the construction of a building for offices and workspace, the acquisition of the real estate, the acquisition of a truck, boxes and containers for the materials and various equipment for administrative and dismantling staff.

Material composition The material composition indicates the share of each material in a device.

Material costs The costs that are caused by supplying the processed material to downstream processing companies (transport costs included).

Material income The income that is generated by supplying the processed material to downstream processing companies (transport costs included).

Material revenue The balance of material costs and income that are caused by supplying the processed material to downstream processing companies

Pre-processing The aim of the pre-processing is to liberate the materials, to separate the contaminants and direct them to adequate subsequent downstream processes. It comprises the handling and sorting of the obsolete appliances as well as their manual dismantling and mechanical processing. (StEP 2009)

Public Relations Public relations (PR) comprises marketing and awareness raising. It thus refers to any action or measure which aims to the dissemination of information about the business and to the awareness raising of waste problems and opportunities.

Purchase costs Covers the purchase of e-waste (from informal sector and B2B).

Refurbishment Refurbishment comprises any action necessary to restore a unit up to a defined condition in function and form that may be inferior to a new unit. The output product meets the original functionality specifications. To refurbish a product requires disassembling the unit only to the extent that is required to ensure the testing and reprocessing of all components not meeting these specifications. The unit's composition and design is not changed significantly. The term *recondition* is understood synonymously for refurbish (StEP 2009).

Repair Repair comprises any action necessary to correct any faults in a unit preventing its specified operation. The output product is in functioning condition. To repair a unit requires only process steps necessary to restore the specified operation. The unit's composition and design is not changed significantly (StEP 2009).

Reuse Reuse of electrical and electronic equipment or its components is to continue the use of it (for the same purpose for which it was conceived) beyond the point at which its specifications fail to meet the requirements of the current owner and the owner has ceased use of the product (StEP 2009).

Running costs All running costs of the business, not considering material revenue and purchase costs. This includes the costs of administration, collection, treatment, CMR , depreciation of investments and other costs.

Scavenger a person who picks out recyclables from mixed waste wherever it may be temporarily accessible or disposed of (GDRC 2011). For the French disambiguation of scavenger, see (GIZ 2010). Scavengers usually belong to the informal sector.

(W)EEE Abbreviation which is introduced in the study; it refers to both waste electrical and electronic equipment (WEEE, obsolete, supplied to the e-waste treatment) and electrical and electronic equipment (EEE, still working, supplied to a refurbishment operation).

List of Abbreviations

B2B	Business to Business
bl	baseline (scenario)
CCFL	Cold cathode fluorescent lamps
CMR	Cleaning, maintenance and repairing
CPU	Central Processing Unit
CRT	Cathode Ray Tube
D.R.Z.	Demontage Recycling Zentrum, Vienna (Austria)
EEE	Electrical and Electronic Equipment
EMPA	Swiss Federal Institute for Material Science and Technology
FR	Flame Retardants
FTE	Full Time Equivalents (= Full Time Employee)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
ICT	Information and Communication Technologies
IS	Informal Sector
KERP	Kompetenzzentrum Elektronik und Umwelt
Li-Ion	Lithium-ion battery
LME	London Metal Exchange
NiMH	Nickel-Metal Hydride battery
PPP	Public-Private Partnership
PWB	Printed Wiring Board
UCPC	Ugandan Cleaner Production Center
USD	US Dollars
WEEE	Waste Electrical and Electronic Equipment
(W)EEE	Waste Electrical and Electronic Equipment as well as Electrical and Electronic Equipment

List of Figures

List of Tables