INVENTORY OF POP-PBDEs IN ELECTRICAL AND ELECTRONIC EQUIPMENT (EEE) AND RELATED WASTES (WEEE) IN NIGERIA

Acknowledgement:

This case study has been developed and prepared by the Basel Convention Coordination Center - Africa. The valuable contributions of Oladele Osibanjo (Executive Director BCCC - Africa and Professor of Analytical & Environmental Chemistry, University of Ibadan, Nigeria), Joshua Babayemi (Analytical & Environmental Chemistry Unit, Department of Chemistry, University of Ibadan, Nigeria) Omotayo Sindiku (Analytical & Environmental Chemistry Unit, Department of Chemistry, University of Ibadan, Nigeria) and Dr. Roland Weber (POPs Environmental Consulting, Germany) who developed, compiled and edited the case study are acknowledged.

1 Introduction

In Nigeria, the import of used electrical and electronic equipment (EEE) from industrial countries increased during the last ten years including in particular non functioning waste electronic and electric equipments (WEEE). These are exported from industrial countries (e.g. Europe and North America) into Nigeria as used equipments for reuse and are of concern for the environmental and human health (Ogungbuyi et al. 2012; Nnorom and Osibanjo, 2008)[1,2]. A part of this is repaired and workers earning a living from the informal sector have developed meanwhile high ability in repairing and refurbishing of used electrical electronics equipment for local resale. This in turn has increased the import of used and waste electrical and electronic equipment from industrial countries[3,4].

While ferrous metals, aluminium and copper have high recovery rates, the precious metals and plastics are only recovered to some extent. For the recovery of metals and as a simple waste management approach the plastic is frequently burned or otherwise dumped (Ogungbuyi et al. 2012)[1]. This practice is of high environmental concern considering that the recovered plastics partly contain Stockholm Convention listed polybrominated diphenyl ethers (POP-PBDEs), other brominated flame retardants (BFRs) and heavy metals. Environmental contamination has been reported from WEEE processing in African countries[3,5] in this respect.

Some challenges related to such practices include the lack of appropriate collection and storage strategies, ensuring that high volumes of valuable and non-valuable waste fractions are stored in an environmentally sound manner and further treated and disposed of.

To address this challenge Nigeria has recently conducted an E-waste inventory under the framework of the implementation of the Basel Convention (Ogungbuyi et al. 2012)[1]. Within the Stockholm Convention pilot workshop on the *"Development of the guidances for reviewing and updating National Implementation Plans (NIPs) under the Stockholm Convention (SC) on Persistent Organic Pollutants (POPs)",* Nigeria has conducted an inventory of POP-PBDEs which was based on the EEE/WEEE inventory. Since basic data from an EEE/WEEE inventory is needed for conducting the POP-PBDEs inventory, basic steps of the development of the EEE/WEEE inventory are also described in this case study and details in Ogungbuyi et al. 2012[1].

[1] Ogungbuyi O, Nnorom IC, Osibanjo O, Schluep M (2012) Nigeria e-Waste Country Assessment. Basel Convention Coordinating Centre for Africa (BCCC-Nigeria) and Swiss EMPA, Ibadan,Nigeria and St.Gallen,Switzerland May 2012. http://www.ewasteguide.info/Ogungbuyi_2012_BCCC-Empa

[2]Nnorom IC, Osibanjo O. (2008) Electronic waste (e-waste): Material flows and management practices in Nigeria. Waste Management 28 1472–1479.

[3] Basel Convention E-waste Africa Programme (2011) Where are WEee in Africa. http://www.basel.int/Implementation/TechnicalAssistance/EWaste/EwasteAfricaProject/Publications/tabid/2553/Default.aspx

[4] Puckett, J., Westervelt, S., Gutierrez, R. and Takamyia, Y. (2005). The digital dump, exporting re-use and abuse to Africa. Seattle, WA., USA: The Basel Action Network (BAN). http://ban.org/library/TheDigitalDump.pdf

[5] Brigden, K., Labunska, I., Santillo, D. and Johnston, P. (2008). Chemical contamination at e-waste recycling and disposal sites in Accra and Korforidua, Ghana. Amsterdam, the Netherlands: Greenpeace International. http://www.greenpeace.org/international/Global/international/planet-2/report/2008/9/chemical-contamination-at-e-wa.pdf

2 STEP 1: Planning of the inventory and identification of stakeholders

The first step of the POP-PBDEs inventory process in EEE/WEEE is to define the scope and the objectives of the inventory and to develop a detailed work plan (see section 3.1.) taking into account the following:

- Number of second-hand EEE imports in the inventory year and the previous years during which possibly POP-PBDE containing EEE/WEEE were/are imported (as a basis for estimating EEE stocks);
- Stocks of EEE devices with possible POP-PBDE content (in use, stockpiled and on the market)[6];
- EEE entering the waste stream i.e. WEEE;
- WEEE plastics for recycling (from domestic WEEE and imported WEEE polymer fractions).

In the case of Nigeria, an WEEE inventory was already developed in cooperation with Swiss EMPA and the Regional Basel Convention Center in Ibajan, Nigeria (http://www.ewasteguide.info/files/Ogungbuyi_2012_BCCC-Empa.pdf).

Members of the EEE/WEEE inventory task team included:

- Basel Convention Coordination Center Nigeria ;
- Federal Ministry of Environment, Housing and Urban Development (with responsibility for waste management) and Ministry of Industry;
- Customs authority;
- Internal support (Swiss national institute EMPA); Secretariat Basel Convention;
- Importers and exporters of electronics;
- Retailers of electronics and second-hand electronics;
- Recyclers of WEEE;
- Recyclers and users of polymers from WEEE;
- NGOs working on WEEE.

Additionally for the POP-PBDE inventory following stakeholders were included:

- Stockholm Convention focal point, Federal Ministry of Environment, Housing and Urban Development
- Department of Chemistry, Faculty of Science, University of Ibadan

For the establishment of the POP-PBDE inventory a work plan was developed early March 2012 with a time frame of 8 weeks to compile the information.

Analysis of WEEE plastic samples for an in-depth inventory were done in cooperation with Fraunhofer Institute in Freising/Germany.
Furthermore a contact to Vienna University was established for support of using the free software for substance/material flow analysis STAN[7] from Vienna University for the calculation/visualisation of the Material and Substance Flow Analysis of POP-PBDEs and POP-PBDE containing materials (see below).

[6] Consumers here include households, public and private sector institutions and organizations.
[7] http://iwr.tuwien.ac.at/resources/downloads/stan.html

The Basel Convention Center in Ibadan, Ibadan University and Swiss EMPA in cooperation with the Federal Ministry of Environment, Housing and Urban Development and selected stakeholders from industrial sector compiled the POP-PBDE inventory.

3 STEP 2: Choosing inventory tiers

For this all three tier levels indicated in the inventory guidance were chosen:

Tier 1: The simple approach of calculating POP-PBDE via per capita CRT was also included although an EEE/WEEE inventory has already been developed in Nigeria. This has been done to compare the data from the different tier levels.

Tier 2: From the developed detailed Nigerian EEE/WEEE inventory the EEE/WEEE data were extracted which contained the information to establish the POP-PBDE inventory with the impact factors listed in the inventory guidance.

Tier 3: Two features from tier 3 approach were selected for improving the inventory

- Establishment of national impact factors in Nigerian Cathode Ray Tube (CRT) polymers from TV and computers by analysing POP-PBDE levels in WEEE plastics;
- Establishment of a material flow assessment of CRT plastic and related substance flow of POP-PBDE.

In addition, a gap analysis has been performed in order to further improve data gathered under tier 2 and tier 3.

4 STEP 3 – Collecting and compiling the data

4.1 Tier 1 inventory approach: Using CRT per capita data

The POP-PBDEs inventory guidance suggests that for the preliminary inventory, a country which has not established any EEE/WEEE inventories can utilize EEE/WEEE data of other countries from the region and extrapolate the per capita value to a reasonable estimate for their own country. For this approach CRT monitors containing the largest share of POP-PBDEs in EEE/WEEE (*PBDE Inventory Guidance*, Stockholm Convention 2012[8]) are used for simplification.

Although Nigeria had already developed a WEEE inventory during an E-waste Africa Project (Ogungbuyi et al. 2012)[1], the tier 1 approached was applied to Nigeria case, to

- Get a first[9] idea on the total amount of POP-PBDEs in the country and the amount of impacted polymers;
- To test all three tier levels and compare the outcomes

[8] Secretariat of the Stockholm Convention (2015) Guidance for the Inventory of commercial Pentabromodiphenyl ether (c-PentaBDE), commercial Octabromodiphenyl ether (c-OctaBDE) and Hexabromobiphenyls (HBB) under the Stockholm Convention on Persistent Organic Pollutants. Draft

[9] The tier 1 calculation only takes a few minutes after reading of the *PBDE Inventory Guidance* (take few hours).

Based on the considerations (as provided in the inventory guidance document section 4.2.1) that

- the average weight of the CRTs (TV or PC monitors) is **25 kg** per device
- and the polymer content **30%**;
- the penetration rate (number of CRTs/capita)
- and the average c-OctaBDE content, for CRT from TV is 0.87 kg/tonne of plastic and computer is 2.54 kg/tonne of plastic (Table 4-11 of *PBDE Inventory Guidance*[8]). The POP-PBDE content in the CRT monitors can be calculated then, with known data of the population in the country and the given range of POP-PBDE values in computer CRTs and TV CRTs.

The c-OctaBDE in CRT was calculated using the following equation:

Estimation using average c-OctaBDE in CRTs (table 4-11 *PBDE Inventory Guidance*[8])

$M_{c\text{-}OctaBDE(i)}$ = No of CRTs/capita$_{Region}$ x population x weight of CRT x % polymer/CRT x c-OctaBDE content

Therefore, using the available information on number of CRTs/capita (0.17) and the population of Nigeria (154.7 million) (as shown in Table 1-A) the following c-OctaBDE and POP-PBDE content in CRTs in Nigeria existed in 2010 based on **tier 1 approach** (Tab. 2-A):

$M_{c\text{-}OctaBDE(i)}$ = No of CRTs/capita$_{Region}$ x population x 0.025 tonnes x 0.3 x range of OctaBDE/tonne polymer (0.87 to 2.54 kg/tonne).

With Tier 1 the total amount of CRTs were estimated to 657,000 tonnes containing 197,000 tonnes CRT polymers.

Considering the impact factors of CRTs (0.87 kg/tonne and 2.54 kg/tonne) between 175 to 500 tonnes of c-OctaBDE could be present in the CRT stocks. Since for the inventory and reporting to COP the listed hexaBDE and heptaBDE from c-OctaBDE needs to be reported, the c-OctaBDE amount is recalculated to POP-PBDEs. Recalculations of c-OctaBDE to POP-PBDEs were done according to table 2-2 of *PBDE Inventory Guidance*[8]. The shares of POP-PBDE in c-OctaBDE are 11% hexaBDE and 43% heptaBDE respectively (table 2-2 in *POP-PBDE inventory Guidance*[8]). Based on this the 175 to 500 tonnes of c-OctaBDE contains 94 to 270 tonnes POP-PBDEs.

Table A-1: Information for calculating c-OctaBDE amount in CRTs in Nigeria Tier I

Indicator	Year	Value	Reference
Total population (millions)	2009	154.7	World Bank (2010)
Number of CRT units per capita	2010	0.17	(table 4-1) *PBDE Inventory Guidance*[8]
Weight of CRT monitor (kg)		25	Section 4.2.1 *PBDE Inventory Guidance*[8]
Amount of polymer fraction in CRT monitor (%)		30	(table 4-11) *PBDE Inventory Guidance*[8]
Amount of c-OctaBDEs in CRT monitors average (kg/tonne)	2010 (EU)	0.87 to 2.54	(table 4-11) *PBDE Inventory Guidance*[8]

Table A-2: POP-PBDEs (kg) in CRT monitor (TV and computer) calculated by the estimated CRT unit per capita

PBDEs in CRTs Nigeria	c-OctaBDE	hexaBDE	heptaBDE
Amount (tonnes)	175 – 500	19 – 55	75 – 215

4.2 Tier 2 inventory approach: Inventory based on Nigerian EEE/WEEE inventory

For conducting an inventory under tier 2, the inventory approach suggested in the *PBDE Inventory Guidance*[8] was followed and the POP-PBDE in WEEE/EEE import, stocks and end-of-life was estimated. As basic data set the detailed data from the EEE/WEEE inventory of Nigeria (Ogungbuyi et al. 2012)[1] were used.

4.2.1 Establishment of EEE/WEEE inventory Nigeria

As mentioned above Nigeria has developed an EEE/WEEE inventory within the African e-waste project and the detailed methodology described in the Nigerian E-waste report (Ogungbuyi et al. 2012)[1].

The main steps were

- Preparations/workshop, organization of the work and data acquisition,
- Material flow assessment of EEE/WEEE in Nigeria and
- Assessment of gaps and limitations.

4.2.1.1 Meetings and workshops

Following workshops and trainings supported the development of the inventory:

- Initial kick off meeting (October 2009);
- Training of enumerators and Government Stakeholder (October 2009) ;
- One day training and debriefing of enumerators for Lagos Inventory, 5th June 2010;
- Midterm review meeting with stakeholders 28th June – 1st July 2010;
- Other specific trainings (e.g. Port Harcourt Inventory);
- Weekly debriefing from the enumerators to coordinators.

4.2.1.2 Data acquisition

Literature and statistical data on e-waste management practices, available technologies, and community participation in e-waste management were collected from the Internet (www.e-waste.info). Specific reports, databases, national statistics on census, press reports and publications from private sector stakeholders, were sources of data utilized in the study.
National data base for information assessed for the importation of EEE included:

- Manifests of shipments of new and used electronics into Nigeria;
- Data from the National Bureau of Statistics;
- Data from the Nigerian Customs Service;
- Interviews of personnel of the NPA and Customs and importers;
- Pictures during inspections and field visits.

Consultations were made with key officials of the regulatory bodies with responsibility for environmental issues, waste management, and port operations, which include the Federal Ministry of Environment (FMENV), the National Environmental Standard and Regulations Enforcement Agency (NESREA), the Lagos State Environmental Protection Agency (LASEPA), Lagos State Waste Management Authority (LAWMA), Kano State Ministry of Environment, Nigerian Port Authority (NPA) and the Nigerian Customs.
Previous inventories and registers from the Lagos State Environmental Protection Agency (LASEPA) were reviewed (Ogungbuyi et al. 2012)[1].

4.2.1.3 Surveys and Field Studies

Comprehensive questionnaires[10] were designed, pre-tested and administered to various stakeholders. The questionnaires were filled in by the research team based on face to face interviews with the corresponding stakeholder.

On-the-spot evaluation was carried out at selected facilities including port terminals, recyclers, refurbishers, retailers, refuse dump sites and recycle shops/markets and households (consumers) of EEE. The study team also participated in the inspection/examination of imported goods at some port terminals. Comprehensive data on the importation of EEE into the country from the National Bureau of Statistics was assessed.
Field studies involved distributing questionnaires and oral interviews to obtain information such as quantity, quality and brands of export purchased, number of years stored before disposal and mode of disposals from different sectors (institutions, government, large businesses and households). This exercise was conducted by environmentalists, socio-economists and assisted by project assistants from NGO's, Environmental Protection Agencies, private sector and the Nigerian Ports.
By these measures the inventory data for the country could be gathered and a robust inventory could be established (Ogungbuyi et al. 2012)[1].

4.2.2 POP-PBDEs in import of EEE/WEEE and time trends

For the calculation of the imported POP-PBDE not only the specific inventory year (2010) was assessed but also all available import data (from 2000 to 2010) were chosen to:

- Make an assessment of the import trends;
- To compare the accumulated EEE/WEEE imports with the EEE/WEEE data on stocks to understand;
- To develop the material flow and substance flow analysis (see below).

The POP-PBDEs in EEE/WEEE imported in each year were calculated using the formula from the *POP-PBDE Inventory Guidance*[8]:

$M_{PBDE(i)} = M_{EEE(j)} * f_{Polymer} * C_{PBDE(i);Polymer}$

Where:

[10] Relevant questionnaires developed in the E-waste Africa project are included as Annex in the *PBDE Inventory Guidance*[8].

- $M_{PBDE(i)}$ is the amount of POP-PBDEs (*i*) in [kg]
  (in Polymer (*k*) of electric and electronic equipment (EEE) (*j*))
- $M_{EEE(j)}$ is the amount of EEE (*j*) in [in tonnes]
  (imported, stockpiled or entering the waste stream)
- $f_{Polymer}$ is the total polymer fraction in [weight-%]
- $C_{PBDE(i);Polymer}$ is the content of the POP-PBDEs (*i*) in the total polymer fraction in [kg/tonne]

With the values described above

$M_{PBDE(i)} = M_{EEE(j)}$ 0.3 x 0.0012

The data of imported used EEE/WEEE for each year (2000-2010) are shown in Table A-3 and the corresponding CRT amount is listed in Table A-4 (Ogungbuyi et al. 2012)[1].

The results of the calculations are shown in Table A-4 for c-OctaBDE and POP-PBDEs.

A sharp increase in the amount of import of used EEE/WEEE was discovered between 2003 and 2006 (see figure A-1 and A-2)[11], with corresponding increase in POP-PBDEs[12]. In the import statistics of EEE/WEEE the data for 2004 and 2005 were missing. Furthermore values for imports between 2007 and 2008 were low and did not fit into the trend with high imports in 2006 and 2009. The explanation given from the data source (Basel/EMPA 2012) showed a possibility of mix-up in data handling. Therefore in the current calculation, the values for these years were estimated by extrapolation[13] and the results are shown in Table A-4. The EEE/WEEE import decreased considerably in 2010 (probably due to enforcement of a law on import of WEEE into Nigeria).

[11] One reason for the increase of WEEE in these years is the change of WEEE import policy of China which until 2005 was the main importer of the worlds WEEE.

[12] One major reason for this increase might be that China restricted WEEE import in 2006 and the flow therefore diverted to other countries and regions including some African countries.

[13] This approach could be a suggestion to other countries that may encounter similar problem in the course of the inventory.

Table A-3: Nigeria EEE/WEEE import statistics for 2000 – 2010 for (in tonnes) according to UN Comtrade database (Ogungbuyi et al. 2012)[1]

WEEE Cat.*	2000	2001	2002	2003	2006	2007	2008	2009	2010
1	50,500	51,200	38,900	87,500	329,800	51,800	42,700	631,900	220,400
2	12,000	15,900	15,400	15,300	87,900	3,000	3,600	52,600	4,900
3	5,300	6,300	9,000	23,100	409,300	50	50	644,100	41,900
4	44,400	48,800	68,900	58,900	1,967,400	2,200	400	1,482,300	135,900
Total	112,200	122,200	132,200	184,800	2,794,400	57,050	46,750	2,810,900	403,100

* The WEEE categories 1-4 classification[14] includes large household appliances (1), small household appliances (2), IT and telecommunications equipment (3), and consumer equipment (4). The PC CRTs are included in category 3 and TV CRTs are included in category 4.

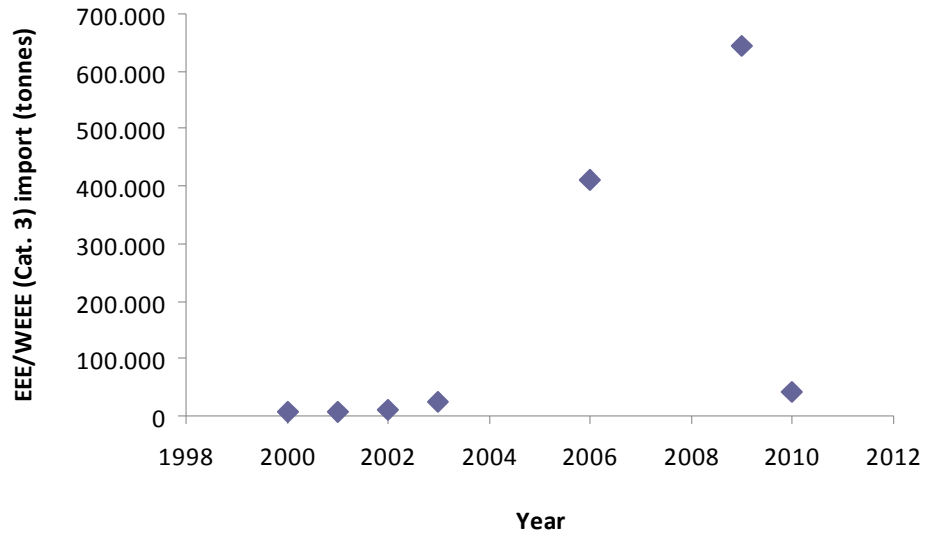

Figure A-1: Import of commercial OctaBDE via Cat. 3 (IT and telecommunications equipment) using computer CRT as tracer

[14] EU Directive 2002/96/EC of the European Parliament and the council on waste electrical and electronic equipment (WEEE)

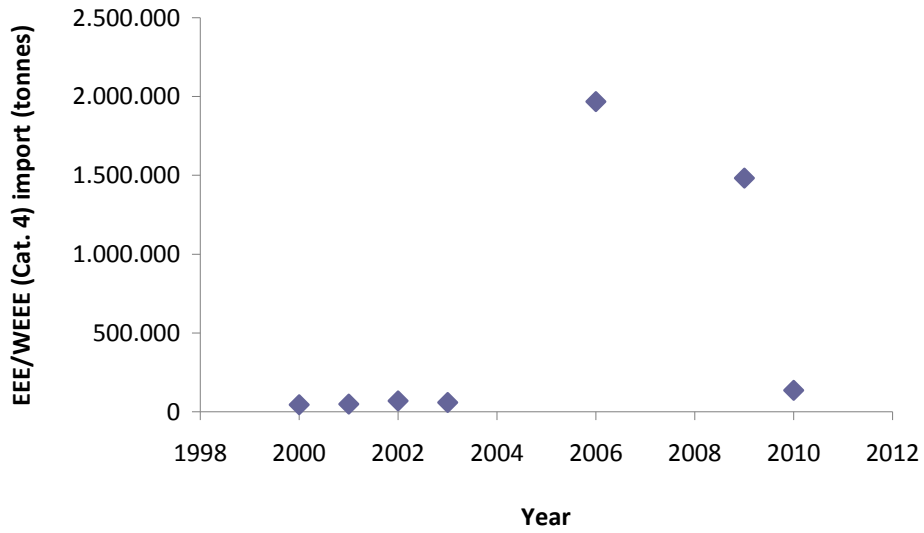

Figure A-2: Import of commercial OctaBDE via Cat. 4 (IT and telecommunications equipment) using TV CRT as tracer

Table A-4: EEE/WEEE import statistics 2000 – 2010 for Nigeria (in tonnes) and corresponding estimated c-OctaBDE and POP-PBDE contents (tonnes)

Year	**WEEE**		**Polymer content of CRT monitor****		**Total Polymer content**	**c-OctaBDE**	**Hexa BDE**	**Hepta BDE**
	Cat. 3	**Cat. 4**	PC	TV				
2000	5,300	44,400	120	5 660	5 780	5.3	0.6	2.3
2001	6,300	48,800	140	6 220	6 360	5.9	0.7	2.5
2002	9,000	68,900	200	8,780	8,980	8.3	0.9	3.6
2003	23,100	58,900	520	7,510	8,030	8	0.9	3.4
2004	140,000	500,000	3,150	63,750	66,900	65	7.2	28
2005	180,000	520,000	4,050	66,300	70,350	69	7.6	30
2006	409,300	1,967,400	9,200	250,800	260,000	247	27	106
2007	260,000*	560,000*	5,850	71,400	77,250	78	8.6	34
2008	300,000*	580,000*	6,750	73,950	80,700	83	9.1	36
2009	644,100	1,482,300	14,500	189,000	203,500	205	23	88
2010	41,900	135,900	940	17,330	18 270	18	2	7.7
Total	2,019,000	5,966,600	45,400	760,700	806,100	793	87	341

* Interpolated numbers

**Of Cat. 3, PC CRT is 7.5%; and of Cat. 4, TV CRT is 42.5%; and polymer content is 30% of CRT monitor

Calculation of POP-PBDE in imports of WEEE/EEE for the inventory year 2010

$M_{PBDE(i)} = M_{EEE(j)} * f_{CRT} * f_{Polymer} * C_{PBDE(i);Polymer}$

c-OctaBDE (PC CRT) = 41,900 tonnes x 0.075 x 0.3 x 2.54 kg c-OctaBDE/tonne = **2.4 tonnes**

c-OctaBDE (TV CRT) = 135,900 tonnes x 0.425 x 0.3 x 0.87 kg c-OctaBDE/tonne = **15.1 tonnes**

C-OctaBDE in non-CRT-polymers of category 3 and category 4[15]

- other EEE category 3[15] polymer (without CRT) = 11627 tonnes
  calculation of c-OctaBDE: 11627 tonnes x 0.225 kg c-OctaBDE/tonne **= 2.6 tonnes**
- other EEE category 4[15] polymer (without CRT) = 23443 tonnes
  c-OctaBDE 23443 tonnes x 0.15 kg c-OctaBDE/tonne = **3.5 tonnes**

4.2.3 Polymer and POP-PBDEs in current stock (in use and stockpiled) of EEE/WEEE

According the Nigerian EEE/WEEE inventory, the total amount of used EEE/WEEE in Nigeria in 2010 was 6,800,000 tonnes (Ogungbuyi et al. 2012)[1]. From these, 946,000 tonnes were from EEE category 3[15] and 1,659,000 tonnes of EEE category 4[15].
Hence **POP-PBDEs for WEEE in stock** can be calculated using the formula:

$M_{c\text{-}OctaBDE;\ EEE(j)} = M_{EEE(j);stockpiled} * f_{Polymer} * C_{c\text{-}OctaBDE;Polymer}$

Whereas:

- $M_{c\text{-}OcctaBDE;stockpiled\ EEE(j)}$ is the amount of c-OctaBDE in stockpiled EEE(j) in [kg]
- $M_{EEE(j);stockpiled}$ is the amount of stockpiled EEE(*j*) in [in tonnes] see section 4.7.1
- $f_{Polymer}$ is the total polymer fraction in EEE(j) in [weight-%]
- $C_{OctaBDE;Polymer}$ is the content of the c-OctaBDE in the total polymer fraction of EEE(j) in [kg/tonne]

The calculations is done in three steps:
1) amount of CRTs
2) amount of plastic of CRTs and
3) amount of c-OctaBDE in plastic of CRTs

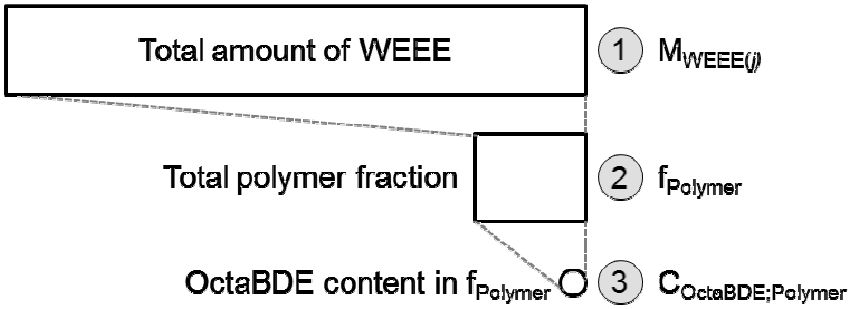

Figure A-: Scheme to estimate the amount of c-OctaBDE in EEE entering the waste stream (WEEE)

Considering the 7.5 % of CRT contribution for EEE category 3[15] and the 42% of CRTs TVs share for EEE category 4[15], the total amount of respective CRT monitors can be calculated. Considering additionally the average of 30% polymers in CRTs then the respective polymer fraction can be calculated:

- PC CRT monitors: 946 000 tonnes Cat 3 EEE/WEEE x 0.075 = 70950 tonnes
  and related PC CRT polymer content: 70 950 tonnes x 0.3 = 21 285 tonnes
- TV CRT monitors: 1,659,000 tonnes Cat 4 EEE/WEEE x 0.425) = 720375 tonnes
  and related TV CRT polymer content = 720 375 x 0.3 = 216 113 tonnes

[15] EEE/WEEE categories according to the European WEEE directive
http://www.environment-agency.gov.uk/business/topics/waste/32120.aspx

These volumes of CRTs and CRT polymers need to be managed to address the POP-PBDEs:

The total c-OctaBDE and POP-PBDE content can be calculated with respective impact factors:
c-OctaBDE in PC CRTs : 21 285 tonnes x 2.54 kg c-OctaBDE/tonne = **54 tonnes**
c-OctaBDE in TV CRTs: 216,113 tonnes x 0.87 kg c-OctaBDE/tonne = **188.0 tonnes**

C-OctaBDE in non-CRT-polymers

- other EEE category 3[15] polymer (without CRT) = 376035 tonnes
  calculation of c-OctaBDE: 376035 tonnes x 0.225 kg c-OctaBDE/tonne **= 84.6 tonnes**
- other EEE category 4[15] polymer (without CRT) = 182047 tonnes
  c-OctaBDE 182047 tonnes x 0.15 kg c-OctaBDE/tonne = **27.3 tonnes**

The respective POP-PBDE amount (**45.7 tonnes** and **14.7 tonnes respectively**) are listed in table 5-A.

Therefore despite the approx. one order of magnitude lower c-OctaBDE impact factor of non-CRT polymers in EEE category 3 and 4 (see table 4-11 *POP-PBDE Inventory Guidance*) a relevant amount of POP-PBDE is present in these plastic fraction due to the large volume. However still the CRT polymers contained more than 75% of POP-PBDEs of the EEE/WEEE sector.
For EEE category 1 and 2 (large and small household appliances)[15] and other EEE categories no impact factors in the *POP-PBDE Inventory Guidance* have been suggested since the POP-PBDE levels in the monitoring study in the EU have been found low and often non detected (Waeger et al. 2010)[18].

Table A-5: Total c-OctaBDE and POP-PBDE (tonnes) in TV and PC CRT monitors in stocks.

Used EEE/WEEE	c-OctaBDE	hexaBDE	heptaBDE
CRT PC	54	5.9	23.2
CRT TV	188	21	81
Category 3 polymers without CRTs	84.6	9.3	36.4
Category 4 polymers without CRTs	27.3	3	11.7
Total	354	39	152

4.2.4 POP-PBDEs in WEEE plastic entering the waste stream in 2010

The amount of EEE entering the waste stream (WEEE) is important for planning the waste and resource management of this critical material flow within a country.
The amount of POP-PBDE entering the waste stream (for the year 2010) was derived from the Nigerian EEE/WEEE inventory. In total 236,500 tonnes of Cat. 3 WEEE with 7.5% PC CRT (total 17738 tonnes including 5321 tonnes CRT plastic); and 331,800 tonnes of WEEE

in category 4 with 42.5% TV CRTs (141,015 tonnes including 42,305 tonnes CRT plastic) were entering the end-of-life and needed waste management.

The amount of c-OctaBDE and POP-PBDE was done with the standard formula:
$M_{c\text{-}OctaBDE;WEEE(j)} = M_{WEEE(j)} * f_{Polymer} * C_{c\text{-}OctaBDE;Polymer}$

c-OctaBDE (PC) = 236,500 x 0.075 x 0.3 x 2.54 = 13516 kg
c-OctaBDE (TV) = 331,800 x 0.425 x 0.3 x 0.87 = 36805 kg
The recalculation of the c-OctaBDE to POP-PBDE is shown in Table A-7.

Table A-7a: c-OctaBDE and POP-PBDEs (kg) entering the waste stream (for the year 2010)

WEEE Category	c-OctaBDE	hexaBDE	heptaBDE
CRT PC	13,516	1,487	5,812
CRT TV	37,651	4,142	16,190
Other Category 3 polymers	6,345	698	2,729
Other Category 4 polymers	5467	601	2351
Total	62,976	**6,928**	**27,082**

4.2.5 POP-PBDE in WEEE plastic in end-of-life (recycling, open burning and disposal)

A key question for the implementation of the Stockholm Convention is the recycling of POP-PBDE containing materials in the end-of-life phase and the related exemption for recycling.
In the 236,500 tonnes of category 3 WEEE (containing 97201 tonnes of plastic) with 7.5% PC CRT (total 17738 tonnes including 5321 tonnes CRT plastic); and 331,800 tonnes of WEEE in category 4 (containing 88093 tonnes plastic) with 42.5% TV CRTs (141015 tonnes containing 42305 tonnes CRT plastic) were estimated to having entered end-of-life in 2010 and requiring waste management.
During the short study period no solid assessment could be conducted on polymer recycling activities in Nigeria which would allow an estimation of the plastic volume actually recycled. Therefore as a simple approach for this preliminary inventory it was assumed that the WEEE plastic was recycled and thermally treated in the same proportions as the general municipal solid waste in Nigeria: this means a recycling rate of 13%, and a share of thermally treatment/open burning of 16% with the remaining 71% landfilled[16].
With this simple assumption from the 62976 kg c-OctaBDE in WEEE polymers reaching end-of-life, 8187 kg is considered to be recycled (901 kg hexaBDE and 3520 kg heptaBDE) and 10,076 kg c-OctaBDE (containing 1,108 kg hexaBDE and 4,333 kg heptaBDE) was thermally treated and 44,713 kg (4,916 kg hexaBDE and 19,227 kg heptaBDE) ended up in landfills/dumps.
The amount of "thermal treatment" of end-of-life polymers is rather an underestimation since plastic from WEEE is frequently burned in the open and therefore the share is probably higher than this estimate. For recycling there is a considerable uncertainty about this estimate since the data are based on the end-of-life treatment for average waste. Here the estimate of

[16] http://mr-gadget.hubpages.com/hub/Effect-of-waste-disposal-and-recycling-in-Nigeria

recycling of plastics from WEEE is rather an overestimation since polymer recycling is just at the start of development. Since currently plastic recycling facilities are established in Nigeria, a detailed assessment on the situation of plastic recycling is needed in near future and data on plastic in recycling will likely be available then.

In the current inventory development no export activities of WEEE plastic were discovered. Also no specific import of used plastic from WEEE (other than associated with the import of WEEE) where discovered. This is also reflected in the substance flow assessment (figure A-4 and figure A-5).

Table A-7b: WEEE plastic and POP-PBDEs entering the waste stream (in tonnes; for 2010) and assumed treatment considering average end-of-life treatment of Nigerian waste.

Plastic and POP-PBDEs (tonnes)	Total end-of-life	Recycled	Thermally treated	Disposed
CRT PC plastic	5321	692	851	3778
CRT TV plastic	42305	5500	6769	30036
Total POP-PBDE in CRTs	33.9	4.4	5.4	24.1
Total plastic in WEEE cat. 3 & 4	185294	29647	24088	131559
Total POP-PBDE in cat. 3 & 4	44.2	5.8	7.1	31.4

4.2.6 Compilation of inventory data

With the data compiled above the summary table 4-12 of the *PBDE Inventory Guidance*[8] was filled (table A-8).

Table A-8: Commercial OctaBDE and related POP-PBDE (hexaBDE and heptaBDE) in EEE, WEEE (TV/PC CRT and Non-CRT) plastic in Nigeria (in tonnes) (filled table 4-12 from *PBDE Inventory Guidance*[8]

Homologues	Distribution homologues c-OctaBDE	POP-PBDEs in import for inventory year 2010	POP-PBDEs in stocks for inventory year 2010	POP-PBDEs entering the waste stream (WEEE) for inventory year	POP-PBDEs in recycled polymers for inventory year 2010
Total inventoried c-OctaBDE*		24	354	63	8.2
hexaBDE	**11%**	2.6	39	6.9	0.9
heptaBDE	**43%**	10.3	152	27	3.5

*C-OctaBDE contains PBDEs listed (hexa- and heptaBDE) and not listed as POPs (octa-, nona-, and decaBDE), and therefore the sum of hexaBDE and heptaBDE do not correspond to 100% of c-OctaBDE.

4.2.7 Preliminary approach to estimate the POP-PBDE amount having entered end-of-life in history

Although not required by the inventory approach, the amount of POP-PBDE having entered end-of-life in history has been estimated.

Since detailed data on the historic disposal of c-OctaBDE containing materials was missing, for this inventory the following simplified approach was taken:

- only the last 7 years were considered where Nigeria had a high inflow of used EEE/WEEE with related high volumes of end-of-life WEEE (the WEEE amount of former years where considered small).
- it was estimated that a similar amount of WEEE polymers has been generated as waste stream the last 7 years.

Therefore, the estimated total amount of c-OctaBDE in the waste stream from 2004-2010 is estimated to 62976 kg POP-PBDEs/year x 7 years = **440832 kg**

From **440832** kg as the total (cat 3 and 4) c-OctaBDEs in the waste stream for the period 2004-2010, the POP-PBDE (hexaBDE and heptaBDE) were calculated (Table A-9).

The largest share of this has been disposed in Nigeria with another not yet estimated share has been burned (largely by open burning). The amount of recycled polymers has not been estimated in this inventory.

Data on POP-PBDE deposited in history in Nigeria is relevant:

- For a complete inventory of the life cycle of POP-PBDE containing materials
- For the leaching of PBDE from landfills and dumps
- As an input parameter for assessing risks of releases from landfill fires
- For an assessment of risks of the increasing practice of landfill mining

Table A-9: Total POP-PBDEs (kg) in WEEE (EEE category 3 and 4)[15] entering the waste stream from 2004-2010

	c-OctaBDE	hexaBDE	heptaBDE
Total end-of life	**440832**	**48491**	**189557**
Disposed to landfills	**312991**	**35429**	**134585**
Thermally treated	**70533**	**7759**	**30329**
Entered recycling	**57308**	**6304**	**24642**

4.3 Tier 3 inventory approach: Measurement of POP-PBDEs in CRT polymers

4.3.1 Calculation of impact factors of TV CRTs and PC CRTs

Currently only one robust dataset on c-OctaBDE/POP-PBDE content in WEEE polymer is available (Waeger et al. 2010)[17] and was the base for the impact factors of the Stockholm Convention *PBDE Inventory Guidance*[8].

This screening however covered plastic from WEEE recycling facilities in European countries in 2009/2010. The imports and stocks in Nigeria were/are imported from different world regions (Europe and North America but also partly from Asia). Therefore the POP-PBDE might be different considering variations production and use have differed (see chapter 2 of

[17] Waeger P, Schluep M, Mueller E. 2010. RoHS substances in mixed plastics from Waste Electrical and Electronic Equipment. St.Gallen / Switzerland: Empa, Swiss Federal Laboratories for Materials Science and Technology. http://ewasteguide.info/files/Waeger_2010_Empa-WEEEForum.pdf

POP-PBDE Inventory Guidance[8]). Furthermore the stock in Nigeria includes many old TVs and computer CRTs from 1980s and 1990s which might be impacted differently compared to the WEEE polymers in the Waeger et al. (2010)[18] study from EU WEEE polymers in 2010. Due to the potential differences of the *PBDE Inventory Guidance*[8] and the Nigerian situation a monitoring project on the POP-PBDE content on CRT devices in stocks in Nigeria has been conducted. The project was supported by the Secretariat of the Stockholm Convention and funding by the Norwegian government.

Following screening and analysis have been performed:

- Overall 382 CRT monitors (224 PC CRTs and 158 TV CRTs; produced between 1980 to 2005 originating from Asia, Europe and North America; brands and model noted) have been screened with XRF for the bromine content (Sindiku et al. 2011)[18]
- All 213 bromine positive tested CRT polymer samples (152 computer CRTs and 61 TVs) were analysed and quantified by GC-ECD and GC-MS for POP-PBDE and other BFRs (Sindiku et al. 2012)[19]

Following impact factors have been derived

- The c-OctaBDE average concentration for 159 TV CRT samples were 0.27% or 2.7 kg c-OctaBDE/tonne polymer and therefore considerably higher compared to the results from the study of WEEE polymers in the EU 2010 (Waeger et al. 2010)[18].
- The c-OctaBDE average concentration for all 224 PC samples were 0.03% or 0.3 kg c-OctaBDE/tonne polymer (and therefore lower compared to the results from the EU study of 0.089%; Waeger et al. 2010[18])

4.3.2 Calculation of POP-PBDEs with Nigerian impact factors

With this derived impact factors for TV and PC CRT monitors in Nigeria the tier 3 inventory was calculated with the same methodology of *PBDE Inventory Guidance*[8] as for the above detailed described tier 2 calculation:

4.3.2.1 Import

c-OctaBDE (PC) = 41900 tonnes x 0.075 x 0.3 x 0.3 c-OctaBDE/tonne **= 0.283 tonnes**
c-OctaBDE (TV) = 135900 tonnes x 0.425 x 0.3 x 2.7 c-OctaBDE/tonne **= 47 tonnes**
Additionally the polymers of other WEEE cat 3 and 4 (without CRT) were estimated to contain 6.1 tonnes of c-OctaBDE based on the impact factors from the inventory. Own factors could be developed in future.

4.3.2.2 Stocks

c-OctaBDE (PC CRTs): 21 285 tonnes x 0.3 kg c-OctaBDE/tonne = **6.39 tonnes**

[18] Sindiku O, Babayemi J.O, Osibanjo O, Schlummer M , Schluep M, Weber R (2011) Screening E-waste plastic in Nigeria for brominated flame retardants using XRF – towards a methodology for assessing POPs PBDE in Ewaste exports. Organohalogen Compounds 73, 785-788 (2011) http://www.dioxin20xx.org/pdfs/2011/1909.pdf
[19] Sindiku O, Babayemi JO, Osibanjo O, Schlummer M, Schluep M, Weber R (2012) Assessing POP-PBDEs and BFRs in E-waste polymers in Nigeria. Organohalogen Compounds 74.

c-OctaBDE in TV CRTs: 216,113 tonnes x 2.7 kg c-OctaBDE/tonne = **584 tonnes**
The related POP-PBDE are calculated in table 9-A.
Additionally polymers of EEE/WEEE category 3 and category 4 (without CRTs) contain the above calculated **112 tonnes** c-OctaBDE including 60.4 tonnes POP-PBDE.

4.3.2.3 End-of-life

c-OctaBDE (PC CRTs) = 236,500 x 0.075 x 0.3 x 0.3 c-OctaBDE/tonne **= 1.6 tonnes**
c-OctaBDE (TV CRTs) = 331,800 x 0.425 x 0.3 x 2.7 c-OctaBDE/tonne **= 114 tonnes**

Additional polymers of WEEE cat 3 and 4 (without CRT) contain 23.4 tonnes c-OctaBDE calculated based on the impact factors from *PBDE Inventory Guidance*[8] (own factors have not yet been developed).

The related POP-PBDE are calculated in table A-10.

4.3.2.4 Polymers-for-recycling

As mentioned above, 13% of polymers entering waste stream was considered being recycling. Hence, 13% (38 tonnes c-OctaBDE) of 139 tonnes in waste steam would end up in recycled polymers.

Table A-10: Commercial OctaBDE and related POP-PBDE (hexaBDE and heptaBDE) in EEE, WEEE (TV/PC CRT and Non-CRT) plastic in Nigeria (in tonnes)

Homologues	Distribution homologues c-OctaBDE	POP-PBDEs in import for inventory year 2010	POP-PBDEs in stocks for inventory year 2010	POP-PBDEs entering the waste stream (WEEE) for inventory year	POP-PBDEs in recycled polymers for inventory year 2010
Total inventoried c-OctaBDE*		59.1	702	139	18
hexaBDE	**11%**	**6.5**	**77.2**	**15.3**	**2**
heptaBDE	**43%**	**25.4**	**302**	**59.8**	**8**

*C-OctaBDE contains PBDEs listed (hexa- and heptaBDE) and not listed as POPs (octa-, nona-, and decaBDE), and therefore the sum of hexaBDE and heptaBDE do not correspond to 100% of c-OctaBDE.

4.4 Comparison of POP-PBDE calculated by the three Tier 3 inventory approach: Measurement of PBDE in CRT polymers

Comparing the result for the inventory of stocks of POP-PBDEs by the tier 1 approach from CRT (175 to 500 tonnes c-OctaBDE containing 79 to 270 tonnes POP-PBDEs) and that of tier 2 approach from CRT data of the Nigerian EEE/WEEE inventory with total 354 tonnes c-

OctaBDE including 191 tonnes POP-PBDEs[20] (see table A-5) it can be concluded that the tier 2 approach within the estimated range of tier 1. The CRT/per capita data from the *POP-PBDE Inventory Guidance*[8] (table 4-1 therein) used for tier 1 estimation was the factor from a preliminary Nigerian e-waste study which was then refined in the full EEE/WEEE inventory (Ogungbuyi et al. 2012)[1] used here for developing of the tier 2 inventory.
The higher POP-PBDE inventory of tier 3 based on own measured data (Sindiku et al. 2011 and 2012)[18,19] were due to the considerably higher c-OctaBDE content in Nigerian TV CRT polymers (0.27%) compared to the impact factor given in *PBDE Inventory Guidance*[8,21] (based on Waeger et al. 2010)[18]. Due to this higher impact factors in TVs CRT, the total POP-PBDE inventory based on tier 3 assessment was 3.4 time higher compared to tier 2 assessment (table A-11).

Table A-11: Comparison of tier 1, 2 and 3 approaches for POP-PBDE inventories of EEE/WEEE stocks (in use and stockpiles) in Nigeria

(tonnes)	c-OctaBDE	hexaBDE	heptaBDE
Tier 1	175 – 500	19 – 55	60 – 215
Tier 2	354	39	152
Tier 3	702	77.2	302

4.5 Material/Substance flow analysis of POP-PBDE containing EEE/WEEE plastic

For compiling the data in a visualized form and to gain an overview on the life cycle of materials containing POP-PBDEs, a material flow analysis (MFA) of these materials and a substance flow analysis (SFA) of the c-OctaBDE and associated POP-PBDEs have been performed.

4.5.1 Material and substance flow analysis

MFAs systematically show the bulk material flows through society in a comprehensive way. The underlying principle of MFA is to account for all materials entering and leaving a system (e.g. country or company), based on a mass-balancing approach. The flow of materials/substance starts at a source (e.g. production or import) and ends at a sink[22] (e.g. export or landfill).

SFA is a specific type of MFA used for tracing the flow of a selected chemical (or group of substances) through a defined system. SFA is a specific type of MFA tool, dealing only with

[20] 368 tonnes c-OctaBDE from CRTs containing 199 tonnes POP-PBDEs plus the additional POP-PBDEs from non-CRT EEE/WEEE polymers of EEE/WEEE category 3 and category 4 of 112 tonnes c-OctaBDE containing 60.5 tonnes POP-PBDE

[21] The impact factor in the *PBDE Inventory Guidance* is based on the only comprehensive study from measuring European WEEE polymers (Waeger et al. 2010). The Nigerian stocks of TVs contain old TVs from 1980s and 1990s probably less present in European WEEE in 2010. Furthermore the European flammability standards the last decade for TV did not necessarily require flame retardant use (standard was changed recently). Therefore it is understandable that the TV CRTs measured in Nigeria contain higher c-OctaBDE compared to impact factor given in the *PBDE Inventory Guidance*[8].

[22] A final sink is defined as a spot within the hydro-, pedo-, litho- or atmosphere, where the retention time of a substance is >10.000 years (Brunner and Rechberger 2003) or where it degrades.

the analysis of flows of chemicals of special interest (Baccini and Brunner 2012[23], Brunner and Rechberger 2003[24]).

A key aim of material flow analysis is to visualise the complex material flow of a selected system (in this case the flow of POP-PBDEs in EEE/WEEE plastic in Nigeria) in a simplified but correct manner to e.g. serve as a tool for decision making in waste management.

In the current study the system boundary is the country Nigeria. The goods included in this study are polymers from category 3 (including PC CRT housing) and category 4 (including TV CRT housing). The substances considered in the substance flow is commercial OctaBDE and in particular the related POP-PBDE homologues (hexaBDE and heptaBDE).
The system comprises the materials of EEE/WEEE in Nigeria and focus on the listed POP-PBDEs which have been used in plastics (hexaBDE and heptaBDEs). The mentioned substances are additive flame retardants applied mainly in ABS and other plastic components of TV/PC CRT monitors. However also other EEE/WEEE in particular of category 3 and 4 are included. The stocks and flows in the system include importation, use/reuse and waste management (recycling, thermal treatment, landfill/dump) and export.

4.5.2 Compilation of quantification and overview of flows and stocks

The strength of the material/substance flow analysis is the visualization of complex material/substance flows. University Vienna provides here one of the best material flow software (STAN) as open source.
The above compiled POP-PBDE inventory data were included in the STAN software for visualizing the POP-PBDE inventory and the related inventory of polymer stocks/flows in EEE/WEEE in Nigeria.
Figure A-3 shows the material flow EEE/WEEE polymers of WEEE category 3 and 4 which will finally need to be managed in an environmentally sound manner. The related substance flow of POP-PBDEs in polymers of WEEE category 3 and 4 is shown in figure A-4 (tier 2) and for the POP-PBDEs in CRTs in Figure A-5. Figure A-6 show the POP-PBDEs in CRT polymers based on measured POP-PBDE data in Nigerian WEEE polymers (tier 3).

[23] Baccini P, Brunner PH (2012) Metabolism of the anthroposphere: Analysis, evaluation, design. 2nd edition, MIT Press, Cambridge US.
[24] Brunner PH, Rechberger H (2003) Practical Handbook of Material Flow Analysis. Lewis Publishers.

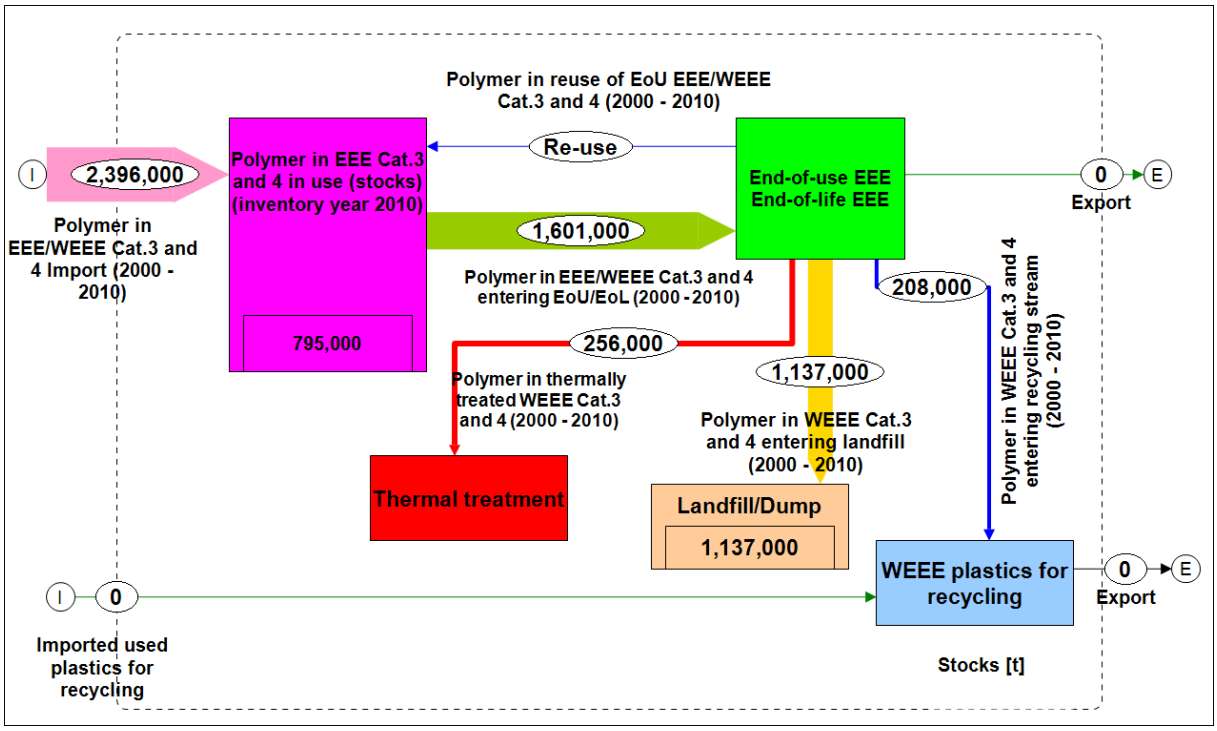

Figure A-3: Material flow of WEEE/EEE polymers (tonnes) of category 3 and 4 in Nigeria (considering the years 2000-2010 for flows[25]; stocks for inventory year 2010)

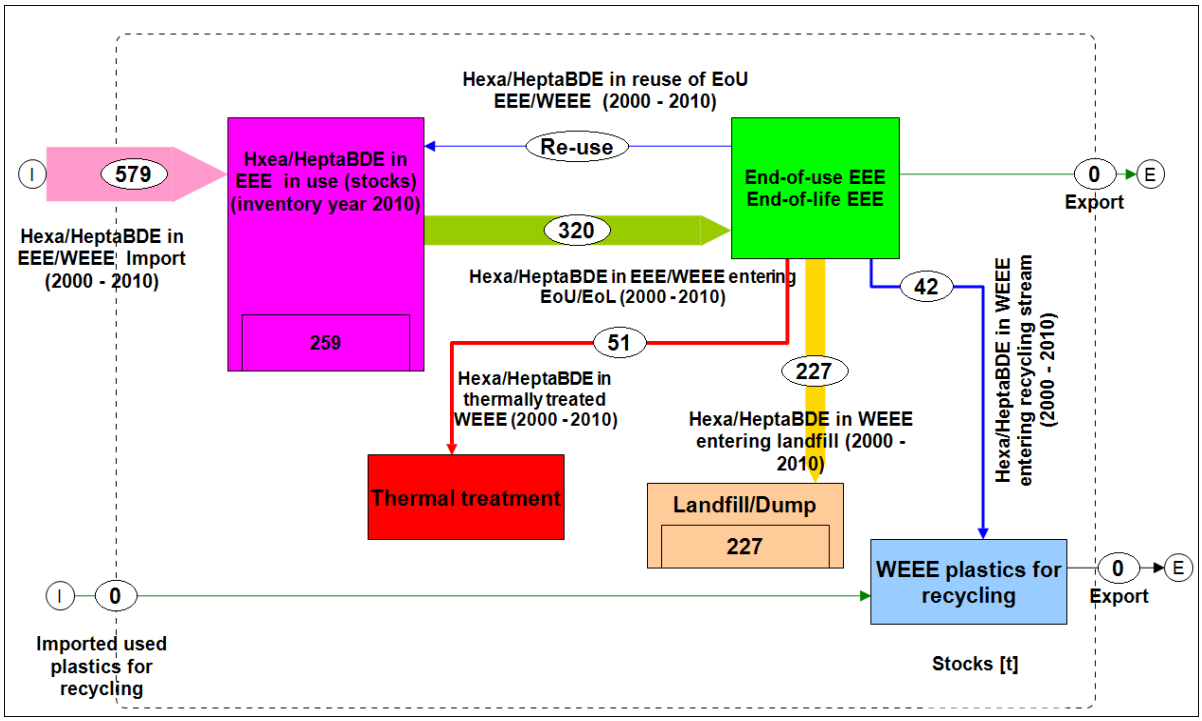

Figure A-4: Substance flow of POP-PBDE (tonnes) in WEEE/EEE polymers in Nigeria in polymers of EEE categories 3 and 4 including CRTs and non-CRT equipment (Tier 2 with factor from *POP-PBDE Inventory Guidance*[8]; considering the years 2000-2010 for flows[25]; stocks for the inventory year 2010)

[25] By considering the EEE/WEEE data of 2000 to 2010 most of total volume of historic EEE/WEEE is covered since the largest inflow of used EEE/WEEE took place from 2005 on.

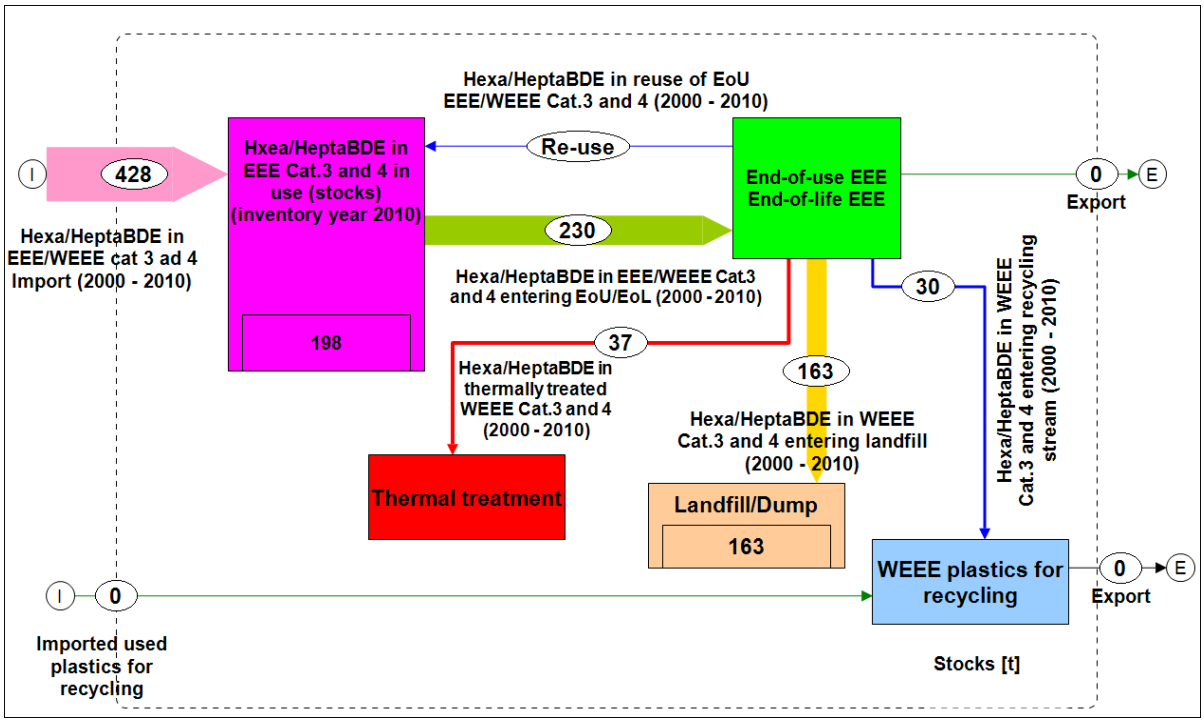

Figure A-5: Substance flow of POP-PBDE (tonnes) in WEEE/EEE polymers of CRTs (TV and computers) in Nigeria (Tier 2 with factor from *POP-PBDE Inventory Guidance;* considering the years 2000-2010[25]; stocks of inventory year 2010)

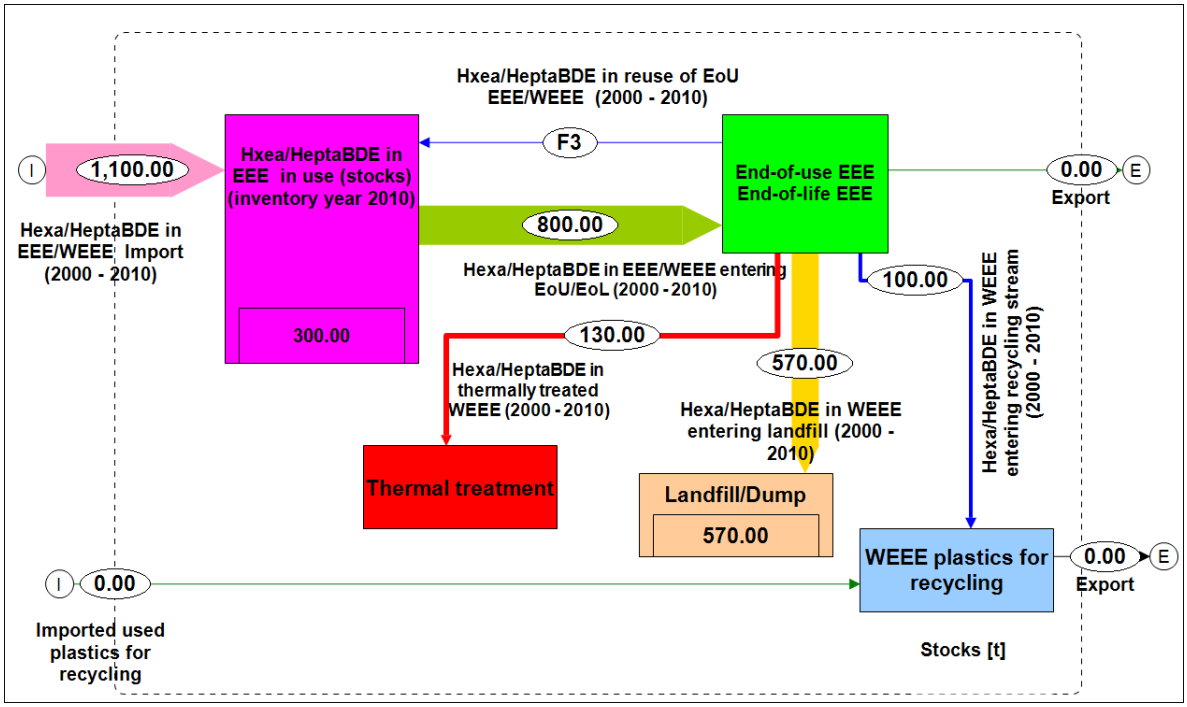

Figure A-6: Substance Flow of POP-PBDEs (tonnes) in CRT polymers in Nigeria (with factor from Nigerian measured data; Tier 3) (Sindiku et al. 2011, 2012)[18,19] (considering the years 2000-2010 in flows[25]; stocks of inventory year 2010).

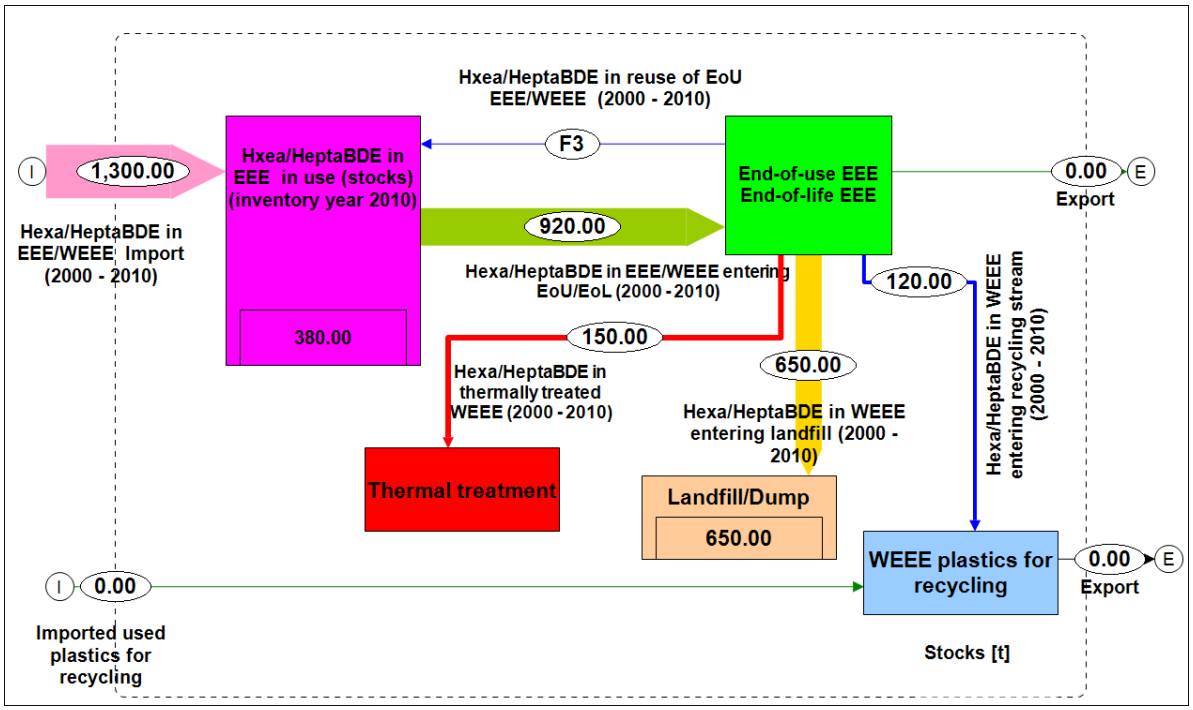

Figure A-7: Substance flow of POP-PBDE (tonnes) in WEEE/EEE polymers in Nigeria in polymers of EEE categories 3 and 4 including CRTs and non-CRT equipment (Tier 3 with factor from Nigerian measured data) (Sindiku et al. 2011, 2012)[18,19] (considering the years 2000-2010 in flows[25]; stocks of inventory year 2010).

5 STEP 4 Managing and evaluating data

5.1 Evaluation of data and further improvement of the data

In this step the data are assessed for completeness and plausibility possibly including the comparison with data from other countries in the region.

It should be noted here that the current described case study has been revised several times and can therefore be regarded already an improved inventory.

In a first compilation of data the values of c-OctaBDE were considerable higher (approx. 5000 tonnes) and would have accounted for 5% of the total historically produced c-OctaBDE. In the reassessment of this first inventory the errors discovered are listed below in 5.2. The major mistake was that the whole polymer fraction of EEE/WEEE has been used instead of the CRT polymer fraction alone and that therefore too high impact factors have been used for the non-CRT polymers.

This show that “reasonability-assessment” of data generated within the development of a POP-PBDE inventory can be very helpful and can reveal calculation mistakes.

Data gaps have (partly) been filled by extrapolation of available statistical data. This was done e.g. in the assessment of import data and in the preliminary estimate of recycled polymers (see above).

The inventory will be further refined and the current and future data are used for deciding on waste management and material recovery. In particular the detailed PBDE/BFR analysis of

the polymer plastic lead to an insight into the contamination status of the CRT WEEE polymer fractions and can be used for decision on recycling options and limitations.
The data have been reviewed by different experts and comments have been considered in this compilation.
Furthermore the data have been compiled in a scientific conference abstract and were submitted to the 32nd International Symposium on halogenated POPs www.dioxin2012.org (Sindiku et al. 2012[26]; Babayemi et al. 2012[27]) for assessment and discussion. In this process the used approach and data will be reviewed by scientists and presented to the POPs research community and subjected to their evaluation. Feedback will be considered in an update of this inventory and also included in the final inventory report and considered for the NIP.

5.2 Some calculation errors made in the earlier assessments

The above described inventory is actually the third PBDE inventory established within this process. The first inventory was
Following mistakes were made in the

- 42% polymer content was used in calculations for computer (which normally should be for WEEE category 3 generally, and not for PC CRT in particular). Also polymer content of 24% was used in calculations for TV (which normally should be for WEEE category 4 generally, and not for TV in particular).

- The amount of category 3 equipment stockpiled is 946 000 tonnes. Of this, PC CRT is just 7.5%; this factor (7.5%) was not considered in the first calculations, and hence resulted in considerable overestimate. Also for TVs, the amount of category 4 equipment stockpiled is 1 695 000 tonnes, of which TV CRT is just 42.5%; this factor (42.5%) was not considered in the first calculations.

- For waste stream (2010) in former calculations, 42% polymer content was used for PC, and c-OctaBDE of 0.225kg/tonnes; and for TV, 24% polymer content, and 0.15 kg/tonnes c-OctaBDE content.

- There were other minor calculation errors (of additions or multiplications)

5.3 Uncertainties and further improvement

As mentioned above, a large uncertainty exists for the percent distribution of end-of-life treatments and on the recycling. This will need larger assessment efforts in particular considering that currently larger plans on polymer recycling exists with resources already allocated. Therefore this is rather a task within the NIP implementation and not for short term improvement of the inventory.
The amount of reuse (electronics from the end-of-use phase refurbished/sold again in the second hand marked) has not been determined in this study.

[26] Sindiku O, Babayemi J, Osibanjo O, Schlummer M, Schluep M, Watson A, Weber R (2014) Polybrominated diphenyl ethers listed as Stockholm Convention POPs, other brominated flame retardants and heavy metals in E-waste polymers in Nigeria. Environ Sci Pollut Res Int. DOI: 10.1007/s11356-014-3266-0
[27] Babayemi J, Osibanjo O, Badejo B, Mojekwu S, Sindiku O, Weber R (2012) PBDE inventory in the transport sector of Nigeria - a step for Stockholm Convention Implementation. Organohalogen Compounds 74, 568-571 http://www.dioxin20xx.org/pdfs/2012/1145.pdf

The current inventory considers polymers of EEE category 3 and category 4. No assessment of the POP-PBDE content in polymers of the other EEE/WEEE categories have been published worldwide with the exemption of some measurements in also analysing some composite samples of other WEEE polymers indicating low to non-detect values for POP-PBDEs (Waeger et al. 2010)[18]. In future more data are needed to become confident that the other EEE/WEEE categories do not contribute to POP-PBDE inventory (as also assumed in this inventory).

5.4 Managing the data

The gathered general inventory data for EEE and WEEE have been compiled and will be included in a database. A report on the EEE/WEEE have been compiled (Ogungbuyi et al. 2012)[1] and this case study have been developed and the data will be sent to the governmental agency responsible for statistics.
Since the data are highly valuable for the (waste) management of EEE and WEEE the data are also made available to departments responsible for waste and resource management in Nigeria (Ministry of Environment and other responsible ministries).
The data will be fed into and further be managed within a database of the governmental body responsible for waste and resource management.

5.5 Data gaps and need for improvements (preliminary action plan consideration)

This substance flow analysis of POP-PBDEs in EEE/WEEE describes the flow from import, use/stocks until the end-of-life including the recycling stage. The amount of re-used EEE has not been quantified in the current assessment. Also there are currently considerable uncertainties in respect to the volumes of recycled polymers and to which products these polymers are recycled. Due to the plan of the government to increase the recycling of polymers this issue need to be better assessed and should become a priority within the action plan of NIP. Within this assessment the options and limitations of POP-PBDEs separation and management will be assessed.
Currently no assessment of the flows/releases of POP-PBDE into the environment and towards human exposure in the different life cycle stages have been performed. This is a future task and might also be included in the action plan.
A detailed assessment in particular of the different end-of-life and recycling option is needed to decide on improvements and on best practice approaches which can be implemented in Nigeria in future.

6 STEP 5 Inventory reporting

In the final step 5 the compiled data are included with the methodology used and the detailed calculation in the POP-PBDE inventory report as an own chapter.
This task has largely been fulfilled with the report you are currently reading. At the same time the report was compiled in a way that it can be used as case study.