ANNEX 2[1]: INVENTORY OF POPs IN ELECTRICAL AND ELECTRONIC EQUIPMENT (EEE) AND RELATED WASTES (WEEE) IN NIGERIA

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[1] This case study is an Annex to the UNEP "Sectoral guidance for inventories of POPs and other chemicals of concern in buildings/ construction, electrical and electronic equipment, and vehicles" Geneva, January 2023.

1 Introduction

Million tonnes of electrical and electronic equipment (EEE) and in particular waste electronic and electric equipment (WEEE) have been imported to Nigeria in the past 25 years and accumulated in the country. Still today the import of about 60,000 t/y of used EEE from industrial countries make a relevant share of EEE including non-functioning WEEE (Nnorom and Odeyingbo 2020)[2]. These are mainly exported from industrial countries (e.g. Europe and North America) into Nigeria as used equipment for reuse and are of concern for the environmental and human health (Nnorom and Osibanjo 2008; Nnorom and Odeyingbo 2020)[2,3]. 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 EEE for local resale. This in turn has increased the import of used EEE and WEEE from industrial countries.[4]

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

To address this challenge Nigeria has conducted an EEE/WEEE inventory under the framework of the implementation of the Basel Convention in 2012 (Ogungbuyi et al. 2012)[5]. Based on this first EEE/WEEE inventory, Nigeria has conducted an inventory of PBDEs[6].

In this case study an update of POPs in EEE/WEEE sector in Nigeria has been conducted including PBDEs listed 2009, decaBDE, HBCD, and POP candidate DP.

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

The first step of the POP inventory process in EEE/WEEE is to define the scope and the objectives of the inventory and to develop a detailed work plan taking into account the following:

- Number of (used) EEE imports in the inventory year and the previous years during which possibly POP containing EEE/WEEE were/are imported (also as a basis for estimating EEE stocks);
- Stocks of EEE devices with possible POP content (in use, stockpiled and on the market)[7];
- EEE entering the waste stream i.e. WEEE;
- WEEE plastics for recycling.

[2] Nnorom IC, Odeyingbo OA (2020) Electronic waste management practices in Nigeria. Handbook of Electronic Waste Management: international best practices and case studies Elsevier BV

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

[4] 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

[5] 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, May 2012. http://www.basel.int/Portals/4/Basel%20Convention/docs/eWaste/EwasteAfrica_Nigeria-Assessment.pdf

[6] Babayemi J, Sindiku O, Osibanjo O, Weber R (2015) Substance flow analysis of polybrominated diphenyl ethers in plastic from EEE/WEEE in Nigeria in the frame of Stockholm Convention as a basis for policy advice. Environ Sci Pollut Res Int. 22, 14502-14514. DOI: 10.1007/s11356-014-3228-6

[7] Consumers here include households, public and private sector institutions and organizations.

In the case of Nigeria, a WEEE inventory was already developed in cooperation with Swiss EMPA and the Regional Basel Convention Center in Ibajan, Nigeria).

Members to update the POPs inventory in Nigerian EEE/WEEE task team included:

- University group in Nigeria working on POPs inventories and on material and substance flow analysis (MFA/SFA) (University of Medical Sciences, Ondo, Nigeria.)
- University group working on EEE/WEEE (Abia State University Uturu, Nigeria)
- International University group working on waste management and MFA/SFA (Technical University Vienna, Austria)
- International consultant experienced in POPs inventories

These University groups cooperated or based information from national stakeholders

- Basel Convention Coordination Center Nigeria ;
- Federal Ministry of Environment, Housing and Urban Development;
- Customs authority;
- Retailers of electronics and second-hand electronics;
- Recyclers of WEEE;
- Recyclers and users of polymers from WEEE;

For the establishment of the POP inventory a work plan was developed with a time frame of 3 month to compile information. Updated information on Nigerian EEE/WEEE was compiled and used as a basis. For the assessment of imports and assessment of the presence of total EEE/WEE in Nigeria, the UN HS Comtrade database[8] for imports were used.

Furthermore a contact to Vienna University was established for capacity building of material and substance flow analysis (MFA/SFA) and a member of Ondo University visited to Vienna University September and October for the calculation/visualisation of the MFA/SFA of POP and POP containing plastic for the case studies for EEE/WEEE (see below) and for POPs in vehicles (See second case study on POPs in transport sector in Nigeria).

3 STEP 2: Choosing inventory methodology

Tier 2: From the developed detailed Nigerian EEE/WEEE inventory the EEE/WEEE data were extracted which contained information to establish the POP inventory with the impact factors listed in the PBDE inventory guidance[9] and Chapter 3 of the sectoral POP inventory guidance[10].

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 PBDE levels in WEEE plastics;
- Establishment of a material and substance flow analysis (MFA/SFA) of EEE/WEEE and related plastic and related substance flow of PBDE.

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

[8] https://comtrade.un.org/

[9] UNEP (2021) Draft guidance on preparing inventories of polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on POPs. Secretariat of the Basel, Rotterdam and Stockholm Conventions.

[10] UNEP (2023) Sectoral guidance for inventories of POPs and other chemicals of concern in buildings/ construction, electrical and electronic equipment, and vehicles.

4 STEP 3 – Collecting and compiling the data

4.1 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*[9] was followed and the PBDE in WEEE/EEE import, stocks and end-of-life was estimated.

4.1.1 EEE/WEEE inventory data 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)[5]. This inventory was updated by considering the imports from UN Comtrade database and service life estimates of the different EEE of major categories considering HS Codes for import and related UNU keys (Table C-1). Also an assignment of PBDE content from the suggested impact factors of the PBDE inventory guidance[9] (see Table C-2) have been made to the individual UNU keys of major EEE/WEEE (Table C-1).

Table C-1: Relevant product categories for the updated EEE inventory and managing PBDEs with reference to their UNU key and HS Code

UNU key	Equipment (according to UNU Key)	Polymer fraction (mean) (%)	hexa/heptaBDE content (mean) in plastics (kg/tonne)	decaBDE content (mean) in plastics (kg/tonne)
101	Professional Heating & Ventilation (1996-2021)	30	0.05	0.8
104	Washing machines (1996-2021)	25	0.05	0.05
106	Household Heating & Ventilation (1996-2021)	30	0.05	0.8
108	Fridge or combined fridge/freezer (1996-2021)	25	0.05	0.05
111	Household Air conditioner (1996-2021)	25	0.05	0.05
308 + 407	CRT monitors + CRT TVs (2000-2010) (**Previous inventory**)	30	0.92	3.8
308	CRT monitors (2011-2021)	30	1.37	3.2
407	CRT TVs (2011-2021)	30	0.47	4.4
303	Laptop, notebook, tablet (2000-2021)	42	0.12	0.8
306	Mobile phones (1996-2021)	24	0.08	0.8
309	Flat panel display for computer (1996-2021)	37	0.009	2.7
408	Flat panels televisions (2009-2021)	37	0.009	2.7
	SUM			

The main steps for updating the POPs in EEE/WEEE in Nigeria were:

- Compiling updated information on EEE/WEEE in Nigeria,
- Assessing the imports of EEE/WEEE to Nigeria
- Selection of service life of individual EEE
- Material and substance flow analysis of EEE/WEEE in Nigeria and
- Assessment of gaps and limitations.

National data base for information assessed for the importation of EEE included:

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

By these measures the inventory data for Nigeria (Ogungbuyi et al. 2012)[5] were updated with data import data for the different WEEE categories needed for the sectoral POP inventory.

Impact factors for decaBDE and for hexaBDE/heptaBDE (from c-OctaBDE) are provided by the PBDE inventory guidance (Table C-2 below; UNEP 2021[9]). Also the share of plastic of the major equipment/WEEE categories are given in Table A2. These are used to update the PBDE inventory in Nigeria in the current study.

Table C-2: Impact factors for decaBDE and hexa/heptaBDE (of c-OctaBDE) and share of polymer fractions in relevant EEE categories (UNEP 2021[9])

Relevant EEE	**Total polymer fraction (mean)**	**Σ hexa/heptaBDE content (mean) in plastics**	**decaBDE content (mean) in plastics**
	$f_{Polymer}$ [in % by weight]	$C_{\Sigma hexa/heptaBDE;Polymer}$ in [kg/tonne]*	$C_{decaBDE;Polymer}$ in [kg/tonne]*
(Cooling/freezing appliances; washing machines)	25%	<0.05	<0.05
Heating appliances	30%	<0.05	**0.8**
Small household appliances	37%	<0.05	**0.17**
ICT equipment. w/o monitors	42%	**0.12**	**0.8**
CRT monitor casings	30%	**1.37**	**3.2**
Consumer equipment w/o monitors (1 composite sample)	24%	**0.08**	**0.8**
TV CRT monitor casings	30%	**0.47**	**4.4**
Flat screens TVs (LCD)	37%	**0.009**	**2.7**

* RoHS limit for c-octaBDE is 1000 mg/kg or 1 kg/t. The Basel provisional low POPs contents for PBDEs are 1000 mg/kg (1 kg/t) or 500 mg/kg (0.5 kg/t) or 50 mg/kg (0.050 kg/t).

The PBDEs in EEE/WEEE were calculated using the formula from the *PBDE Inventory Guidance*[9]: with the impact factors of Table A2

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

Where:

- $M_{PBDE(i)}$ is the amount of PBDEs (*i*) in [kg] (in Polymer (*k*) of 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-%] (from Table C-2)
- $C_{PBDE(i);Polymer}$ is the content of the PBDEs (*i*) in the total polymer fraction in [kg/tonne] (from Table C-2)

The calculations is done in three steps:

1) amount of Respective EEE category
2) amount of plastic of EEE or WEEE
3) amount of PBDE in plastic of EEE categories

4.1.2 PBDEs in import of EEE/WEEE and time trends

Import of WEEE

For the calculation of the imported POP-PBDE not only the specific inventory year (2021) was assessed but also all available import data (from 2000 to 2021) 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 Section 4.3).

The EEE/WEEE categories with the highest PBDE impact factors are Cathode Ray Tube (CRT) casings and flat screen (LCD) of TVs/computers (Table C-2). While other EEE/WEEE had lower impact factors (Table C-2).

4.1.2.1 Calculation of PBDEs in CRTs

The data of imported used EEE/WEEE for each year (2000-2010) are shown in Table C-1 and the corresponding CRT amount (Ogungbuyi et al. 2012)[5] is listed in Table C-3.

The inventory result are shown in Table C-3 for PBDE-2009 and decaBDEs. The CRTs imported to Nigeria 2000 to 2021 contained 2211 tonnes hexa/heptaBDE and 9142 tonnes decaBDE (Table C3). They are contained in 2,405,000 tonnes of WEEE plastic. The distribution of the CRT plastic and the PBDEs in the life cycle stages is compiled in the MFA/SFA in Section 4.3.2.1

Table C-3: Total amount of hexa/heptaBDE and decaBDE in total CRTs plastic in Nigeria

Equipment (according to UNU Key)	Amount of EEE (tonnes)	Polymer fraction (mean) (%)	Amount of Polymer (tonnes)	hexa/heptaBDE content (mean) in plastics (kg/tonne)	Amount of hexa/heptaBDE (kg)	decaBDE content (mean) in plastics (kg/tonne)	Amount of decaBDE (kg)
CRT monitors + CRT TVs (2000-2010)	7,986,667	30	2,396,000	0.92	2204320	3.8	9104800
CRT monitors (2011-2021)	8,689	30	2,606	1.37	3571	3.2	8341
CRT TVs (2011-2021)	22,238	30	6,671	0.47	3135	4.4	29354
SUM	**8,017,594**		**2,405,277**		**2,211,026**		**9,142,495**

4.1.2.2 Calculation of PBDEs in LCDs

The data of imported used LCDs (2000 to 2021) are compiled in Table C-4 with the PBDE inventory result for PBDE-2009 and decaBDEs. The LCDs imported to Nigeria 2000 to 2021 contained 0.78 tonnes hexa/heptaBDE and 234 tonnes of decaBDE (Table C-4). They are contained in 77,400 tonnes of WEEE plastic (Table C-4). The distribution of the LCD plastic and the PBDEs in the life cycle stages is compiled in the MFA/SFA in Section 4.3.2.1.

The low hexa/heptaBDE content result from the stop of c-OctaBDE in 2004 while LCDs were mainly produced after 2006.

Table C-4: Amount of hexa/heptaBDE and decaBDE in total LCD plastic in Nigeria

Equipment (according to UNU Key)	Amount (tonnes)	Polymer fraction (mean) (%)	Amount of Polymer (tonnes)	hexa/ heptaBDE content in plastics (kg/t)	Amount of hexa/ heptaBDE (kg)	decaBDE content in plastics (kg/t)	Amount of decaBDE (kg)
LCD for computer (2000-2021)	4,818	37	1,782	0.009	100	2.7	29,909
LCD televisions (2009-2021)	204,437	37	75,641	0.009	681	2.7	204,232
SUM	**209,255**		**77,423**		**781**		**234,141**

4.1.2.3 C) Calculation of PBDEs in other EEE/WEEE

The data of remaining EEE/WEEE imported (1996 to 2021) are compiled in Table C-4 with the PBDE inventory result for PBDE-2009 and decaBDEs. These EEE/WEEE contained 16.5 tonnes hexa/heptaBDE and 58.8 tonnes of decaBDE (Table C5). They are contained in 301,000 tonnes of WEEE plastic.

Table C-5: Total amount of hexa/heptaBDE and decaBDE in remaining EEE/WEEE plastic (excluding CRTs and LCDs) in Nigeria imported 1996 to 2021

Equipment (according to UNU Key)	Amount of EEE (tonnes)	Polymer fraction (mean) (%)	Amount of Polymer (tonnes)	hexa/heptaBDE content (mean) in plastics (kg/tonne)	Amount of hexa/heptaBDE (kg)	decaBDE content (mean) in plastics (kg/tonne)	Amount of decaBDE (kg)
Prof. Heating & Ventilation	80,019	30	24,005	0.05	1200.285	0.8	19204
Washing machines	2,831	25	708	0.05	35.3875	0.05	35
Household Heating & Ventilation	9,583	30	2,875	0.05	143.745	0.8	2299
Fridge or combined fridge/freezer	490,370	25	122,592	0.05	6129.625	0.05	6129
Household Air conditioner	477,194	25	119,298	0.05	5964.925	0.05	5964
Laptop, notebook, tablet	33,046	42	13,879	0.12	1665.518	0.8	11103
Mobile phones	73,489	24	17,637	0.08	1,411	0.8	14,110
SUM	**1,166,532**		**300,994**		**16,550**		**58,847**

Calculating from the global e-waste data for Nigeria (https://globalewaste.org/statistics/country/nigeria/2019/), the amount of EEE in current use in Nigeria in 2019 contained 1,192,000 tonnes polymers, which is 42% of polymers (2,806,221 tonnes) in total EEE import (1996-2021).

4.1.3 Other POPs in plastic in EEE/WEEE (HBCD, SCCP)

Initial average impact factors of other POPs and POPs candidates have been derived from the national study on POPs in Swiss WEEE plastic (Taverna et al. 2017[11]; the sectoral POP inventory guidance[10] Sections 3.2, 3.3 and 3.4). Additional impact factors for POPs other than PBDEs were for HBCD () and SCCPs (). Further impact factors for POP candidates MCCP () and dechlorane plus () had considerable lower average content compared to PBDEs (Taverna et al. 2017[11]; Sections 3.2, 3.3 and 3.4 of sectoral POP inventory guidance). Non-specific impact Due to their lower relevance and since they are only calculated here for the total plastic in WEEE and current use. The country sheet Nigeria of the Global E-waste Statistic Partnership estimates that in 2019 a total of 461,000 t e-waste Global E-waste Partnership 2022[12]) was generated which contained approx. 92,200 t of plastic. The total amount of EEE introduced 2019 to the Nigerian market was 737,000 t of EEE[12] containing 147,000 t of plastic. Considering an average service life of EEE of 10 years and a linear increase of EEE brought to the market 2009 corresponding to the amount of WEEE 2019 and current new EEE to the market in 2019 (737,000 t) a total amount of approx. 5,960,000 EEE was in use in Nigeria in 2019 containing **1,192,000 t of EEE/WEEE plastic**.

The Swiss national study had an average impact factor for decaBDE in WEEE plastic of 390 mg/kg (Taverna et al. 2017)[11]. DecaBDE is still produced in China and the use in EEE casings is exempted. With this average impact factor it can be estimated that a total amount of 57 t decaBDE were imported in new EEE in 2019. This can be considered an upper estimate since the overall decaBDE production has decreased in the last decade. Further with this average impact factor it is estimated that 465 t of decaBDE are present in EEE in current use and a total amount of 36 t were contained in the WEEE plastic in 2019. This is in the same range as the estimate of the individual EEE/WEEE.

For HBCD with an initial impact factor of 14 mg/kg[11] (see Section 3.3.2 of sectoral POP inventory guidance[10]) a total amount of 7.4 t in EEE in current use and a total amount of 1.3 t in WEEE plastic in 2019 can be calculated. This amount is mainly contained in HIPS. No HBCD (0 t) in new EEE in 2019 is considered since HBCD use in EEE stopped in 2014 after SC listing.

For SCCPs with an initial impact factor of 5 mg/kg (see Section 3.2.2 sectoral POP inventory guidance[10]) and current production and exemption a total amount of 0.74 t in new EEE, 6 t in EEE in current use and a total amount of 0.46 t in WEEE plastic. This amount is mainly contained in cables and other PVC parts.

For MCCP with an initial impact factor of 50 mg/kg (see Section 3.4.3 sectoral POP inventory guidance[10]) and current production, a total amount of 7.4 t in new EEE, 60 t in EEE in current use and a total amount of 4.6 t in WEEE plastic. This amount is mainly contained in cables and other PVC parts.

For dechlorane plus with an initial impact factor of 33 mg/kg[11] (Taverna et al. 2017[11]; see Section 3.4.1 sectoral POP inventory guidance[10]) and current production and exemption, a total amount of 4.9 t in new EEE, 39 t in EEE in current use and a total amount of 3 t in WEEE plastic.

[11] Taverna R, Gloor R, Zennegg M, Birchler E (2017) Stoffflüsse im Schweizer Elektronikschrott. Report for the Swiss Federal Office for the Environment. Umwelt-Zustand Nr. 1717, 164 pp.

[12] Global E-waste Statistic Partnership; Country Sheet Nigeria https://globalewaste.org/statistics/country/nigeria/2019/

4.1.4 Other chemicals of concern in EEE/WEEE

In this first sectoral inventory of POPs in EEE/WEEE, other chemicals of concern were not assessed such as heavy metals (e.g. lead, mercury), ODS/GHGs (CFCs, HFCs), PFRs or phthalates (see Section 4.5 of sectoral POPs inventory guidance[10]). However contacts were made to the Minamata, Basel and Rotterdam focal point to inform on the sectoral POP inventory and on interest to cooperate to a larger sectoral inventory with other MEAs. In the Minamata initial assessment mercury in EEE/WEEE were included to some extent (mercury lamps). It was concluded that in the next assessment, a more detailed mercury inventory in EEE/WEEE should be a part of mercury inventory.

On lead a regulation similar like RoHS and regulatory activities to reduce/eliminate current lead in paints without assessing an inventory of lead or other heavy metals in EEE/WEEE. It was concluded that in the next inventory also lead and selected other metals of concern in EEE/WEE will be assessed.

Also a contact to the Montreal Protocol and the UNFCCC (United Nations Framework Convention on Climate Change) team was established to see if an inventory in EEE/WEE for ODS (CFCs) and GHG (HCFCs, HFCs) stocks have been developed. It was concluded that for future refining of the POPs inventory in EEE/WEEE, synergies with refining ODS/GHG inventories should be explored with the Montreal Protocol and UNFCCC team.

4.2 Tier 3 inventory approach: Measurement of PBDEs in CRT polymers

4.2.1 Calculation of impact factors of CRTs (TVs and PCs)

The robust dataset on POP-PBDE content in WEEE polymer was established in Europe (Waeger et al. 2010[13]; Hennebert et al. 2017[14]) and is the base for the impact factors of the Stockholm Convention *PBDE Inventory Guidance*[9]. 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, North America and Asia). Therefore the PBDE content might be different in different regions considering different regulatory frames (see Chapter 2 of *PBDE Inventory Guidance*[9]; Charbonnet et al. 2020[15]). 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 Europe (Waeger et al. 2010)[13] study from EU WEEE polymers in 2010 in Europe. 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 monitoring project was supported by the Secretariat of the Stockholm Convention and funding by the Norwegian government.

Following screening and analysis have been performed:

[13] 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.

[14] Hennebert P, Filella M. (2018). WEEE plastic sorting for bromine essential to enforce EU regulation. Waste Manag. 71, 390–399.

[15] Charbonnet J, Weber R, Blum A (2020) Flammability standards for furniture, building insulation and electronics: Benefit and risk. Emerg. Contam 6, 432-441, https://doi.org/10.1016/j.emcon.2020.05.002

- 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. 2015)[16]
- All 213 bromine positive tested CRT polymer samples (152 computer CRTs and 61 TVs) were analysed and quantified for PBDE and other BFRs [16]

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 somewhat higher compared to the UNEP impact factor from the study of WEEE polymers in the EU (Waeger et al. 2010) [13].
- The decaBDE average concentration for 159 TV CRT samples were 0.86% or 8.6 kg decaBDE/tonne polymer and therefore higher compared to the UNEP impact factor of 4.4 kg/t from the study of WEEE polymers in the EU 2010 (Waeger et al. 2010) [13].
- The c-OctaBDE average concentration for all 224 PC sampled in Nigeria dumps 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])
- Ten of the 224 computer samples tested contained c-DecaBDE with an average concentration of 1.28% (range 0.26 to 5.4 %) average concentration average concentration of 0.08 % and therefore lower then the UNEP impact factor of 3.2 kg/t from the study of WEEE polymers in the EU 2010 (Waeger et al. 2010).

This shows that for CRT TV casings, the UNEP impact factor from studies in the EU 2010 seems a factor for 2 too low for the old Nigerian CRTs in dump sites. However the difference was only a factor of 2. Since the average CRT TVs in Nigeria in use are likely younger than the sampled CRTs casings which were all produced before 2006, the average PBDE concentration in Nigeria is likely lower than the measured concentration. **Therefore it was decided that the UNEP impact factor is used to calculate the total PBDEs in Nigeria. The same is true for c-OctaBDE (containing hexa/heptaBDE).**

Furthermore the plastic in the sampled 159 CRTs TVs had a total weight of 1.2 tonnes. The Empa guidance for taking an average WEEE plastic sample suggest that the shredder plastic amount for a representative sample should be 3 to 7 tonnes and therefore the Empa sampling was from this perspective more representative.

Similarly the plastic of the 224 computer CRTs had only a weight of 1.7 tonnes and therefore were also less representative. Therefore it was decided that also the impact factor suggested by the UNEP guidance was used for calculating the average PBDEs.

4.3 Tier 3 Material/Substance flow analysis of PBDE containing EEE/WEEE plastic

For compiling the data in a visualized form and to gain an overview on the life cycle of plastics in EEE/WEEE containing POP, a material flow analysis (MFA) of these materials and a substance flow analysis (SFA) for decaBDE and for PBDEs listed 2009 have been performed.

[16] Sindiku O, Babayemi J, Osibanjo O, Schlummer M, Schluep M, Watson A, Weber R (2015) 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. 22, 14489-14501. DOI: 10.1007/s11356-014-3266-0.

4.3.1 Introduction to the 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 (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 the analysis of flows of chemicals of special interest (Brunner and Rechberger 2003[17]).

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

The strength of the material/substance flow analysis is the visualization of complex material/substance flows. University Vienna provides here the open software STAN (short for sub**ST**ance flow **AN**alysis; https://stan2web.net/) which was used for the MFA/SFA.

The above compiled POP-PBDE inventory data were included in the STAN software for visualizing the PBDE inventory and the related inventory of polymer stocks/flows in EEE/WEEE in Nigeria.

In the current study the system boundary is the country Nigeria. The goods included in this study are polymers from major EEE and WEEE. The substances considered in the substance flow are decaBDE, and (W)EEE-relevant PBDE homologues listed in 2009 (hexaBDE and heptaBDE from c-OctaBDE). The stocks and flows in the system include importation, use/reuse and waste management (recycling, open burning, landfill/dump) and export.

4.3.2 MFA/SFA of CRTs and LCDs containing the major amount of PBDEs

4.3.2.1 MFA/SFA for plastic in CRTs casings and related PBDEs

Huge amount of CRTs (computer and TVs) have been imported in the last 25 years to Nigeria as second hand equipment, e-waste and some as new equipment. The CRTs imported between 1996 to 2021 contained approximately 2.4 million tonnes plastic (Figure C-1). Considering a service life of 12 years almost all of CRT casings including the plastic have entered end-of-life the past 20 years (see Figure 1-C). 1.5 million tonnes of CRT plastic was disposed to landfills (64%) while 383,000 tonnes (16%) were burnt in the open and 479,000 tonnes (20%) were reused or recycled.

Figure C-2 and C-3 show the MFA/SFA for hexaBDE/heptaBDE and decaBDE in these CRT plastic which has the same contribution since no specific separation of WEEE plastic has been established I Nigeria up to now. There are however UN projects on WEEE management which might change this situation.

[17] Brunner PH, Rechberger H (2003) Practical Handbook of Material Flow Analysis. Lewis Publishers.

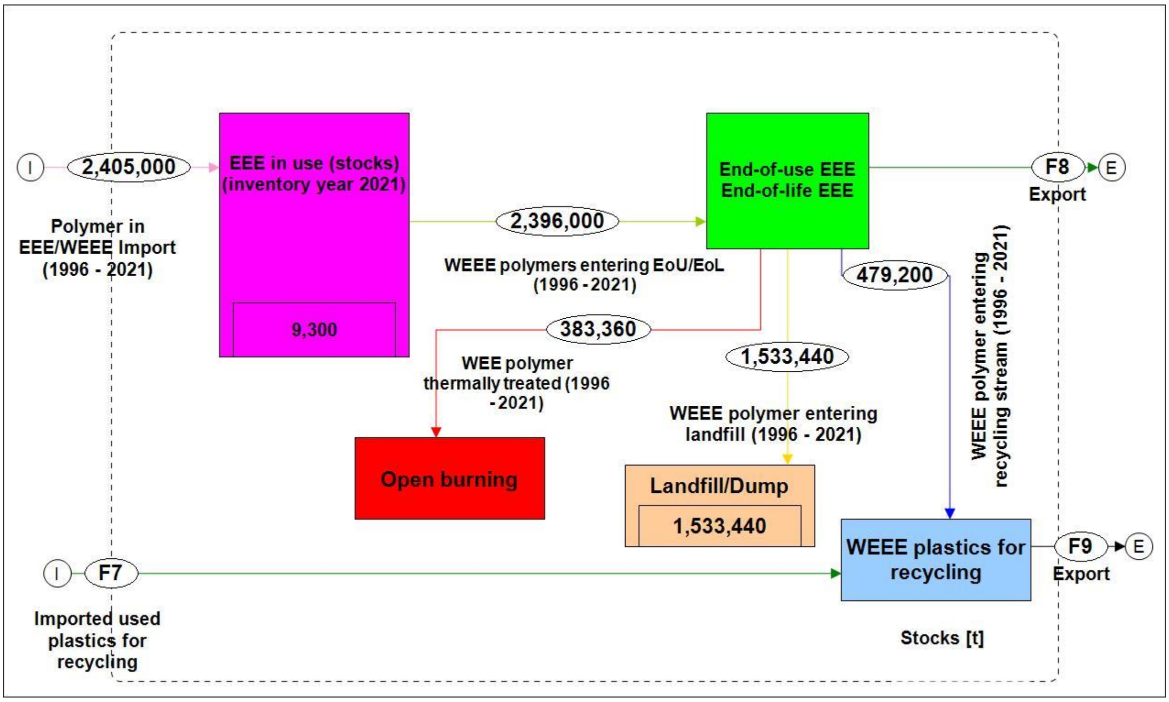

Figure C-1: Material flow of plastic of CRT casing (tonnes) imported to Nigeria with flows (considering 1996-2021) and the stocks for the inventory year 2021.

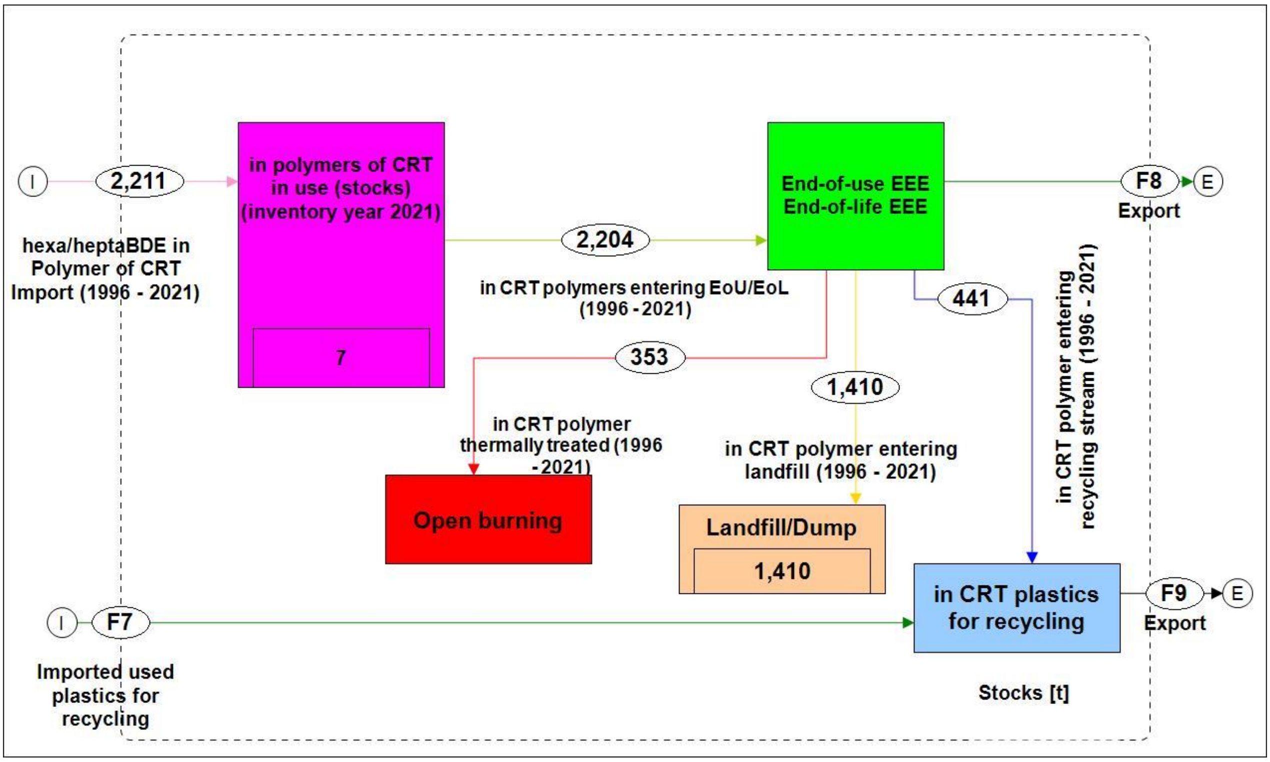

Figure C-2: Substance flow of hexa/heptaBDEs (tonnes) in CRT polymers in Nigeria for flows considering 1996-2021 and the stock in the inventory year 2021

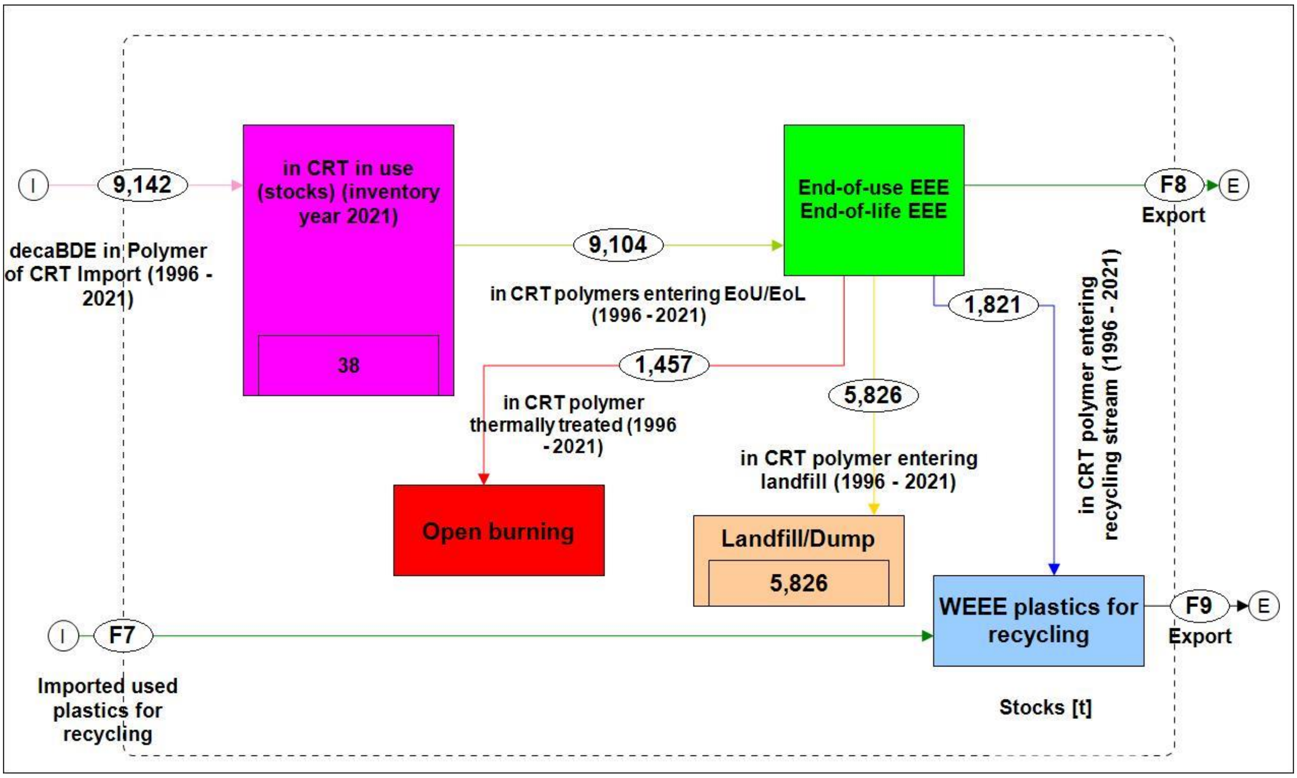

Figure C-3: Substance flow of decaBDE (tonnes) in CRT polymers in Nigeria for flows considering 1996-2021 and the stock in the inventory year 2021

4.3.2.2 PBDE in WEEE plastic in LCDs

Huge amount of LCDs (computer and TVs) have been imported in the last 20 years to Nigeria as second hand equipment, e-waste and some as new equipment. The LCDs imported between until 2021 contained approximately 86,718 tonnes plastic (Figure C-4). Considering a service life of 20 years almost all of LCDs (99%) were still in use or stored at home (see Figure 1-C). 104 tonnes of LCD plastic was disposed to landfills (64%) while 26 tonnes (16%) were burnt in the open and 32 tonnes (20%) were reused or recycled.

Figure C-2 and C-3 show the MFA/SFA for hexaBDE/heptaBDE and decaBDE in these LCD plastic. More than 208 tonnes of decaBDE were still in use in LCDs while only 25 tonnes of decaBDE have entered the waste stream (Figure C-6). From this, more than 16 tonnes decaBDE disposed in LCD plastics to landfills/dump sites. Approximately 4 tonnes of decaBDE were burnt in the open in with LCD plastic (Figure C-6) and associated high releases of brominated dioxins and furans (PBDD/PBDF)[18] accumulating in e.g. chicken and eggs at e-waste burning sites as documented by the highest Dioxin contaminated egg ever measured in the world at such a site in Ghana[19]. It was estimated that about 5 tonnes of decaBDE was recycled (Figure C-6) into new plastic products.

[18] Weber R, Kuch B (2003) Relevance of BFRs and thermal conditions on the formation pathways of brominated and brominated-chlorinated dibenzodioxins and dibenzofurans. Environ Int. 29, 699-710.

[19] Petrlik J, Bell L, DiGangi J, Allo'o Allo'o SJ, Kuepouo G, Ochola GO, Grechko V, Jelinek N, Strakova J, Skalsky M, Drwiega YI, Hogarh J, Akortia E, Adu-Kumi S, Teebthaisong A, Carcamo M, Beeler B, Behnisch P, Baitinger C, Herold C, Weber R. (2022) Review: Monitoring of Dioxins and PCB in Eggs as Sensitive Indicator

The hexa/heptaBDE in LCD plastic were less than 1 t (780 kg) and therefore less than 0.5% of decaBDE. As for decaBDE most of hexa/heptaBDE (695 kg) were still in use in LCDs.

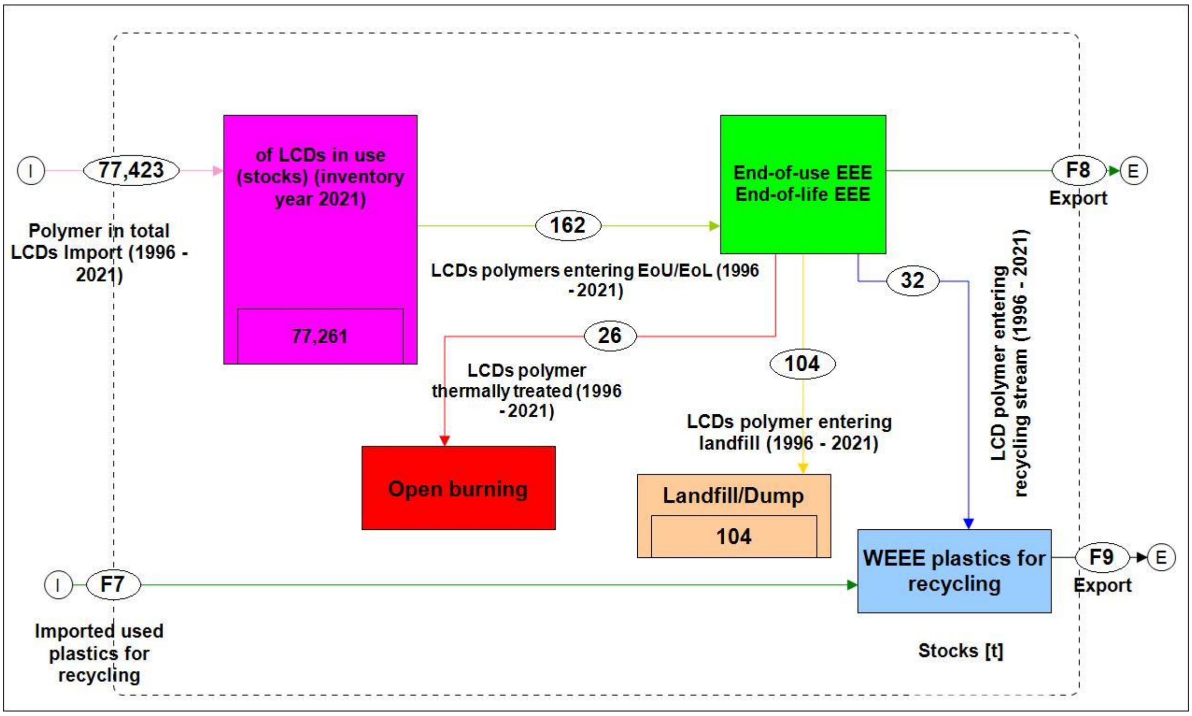

Figure C-4: Material flow of plastic of LCDs (tonnes) imported to Nigeria with flows (considering 2000-2021) and the stocks for the inventory year 2021.

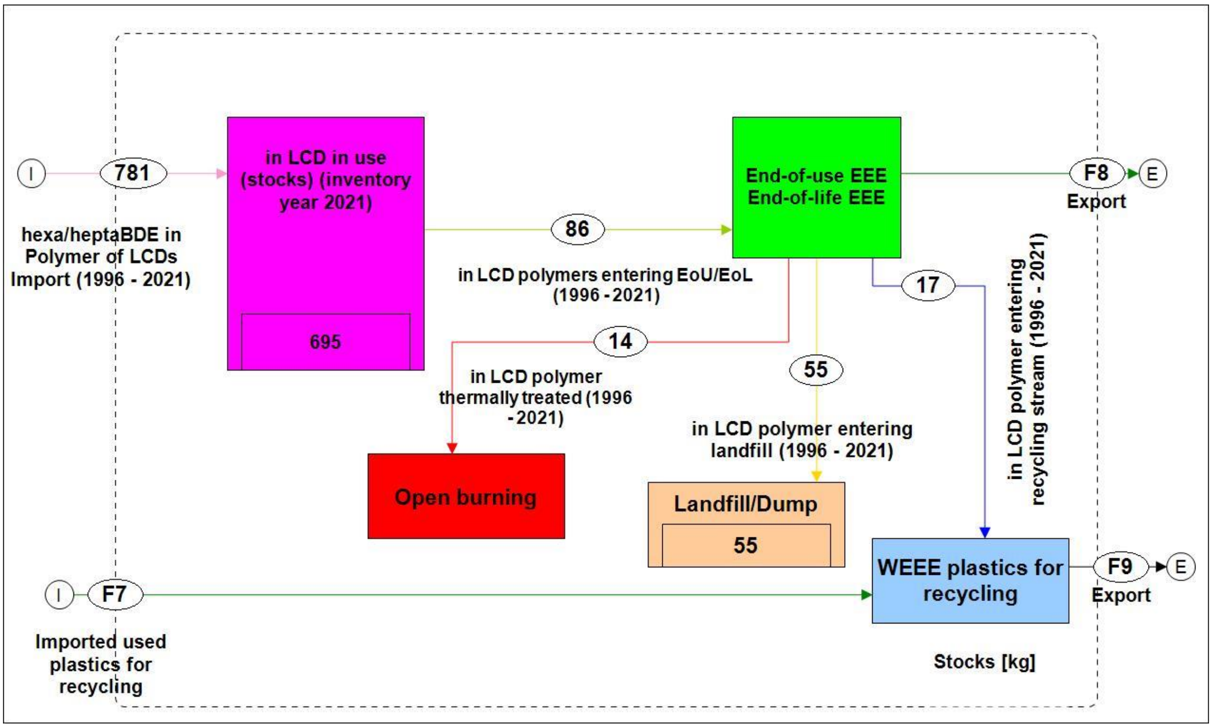

Figure C-5: Substance flow of hexa/heptaBDE (tonnes) in CRT polymers in Nigeria for flows considering 2000-2021 and the stock in the inventory year 2021

for Environmental Pollution and Contaminated Sites and Recommendations for Reducing and Controlling Releases and Exposure. Emerg. Contam. 8, 254-279 https://doi.org/10.1016/j.emcon.2022.05.001

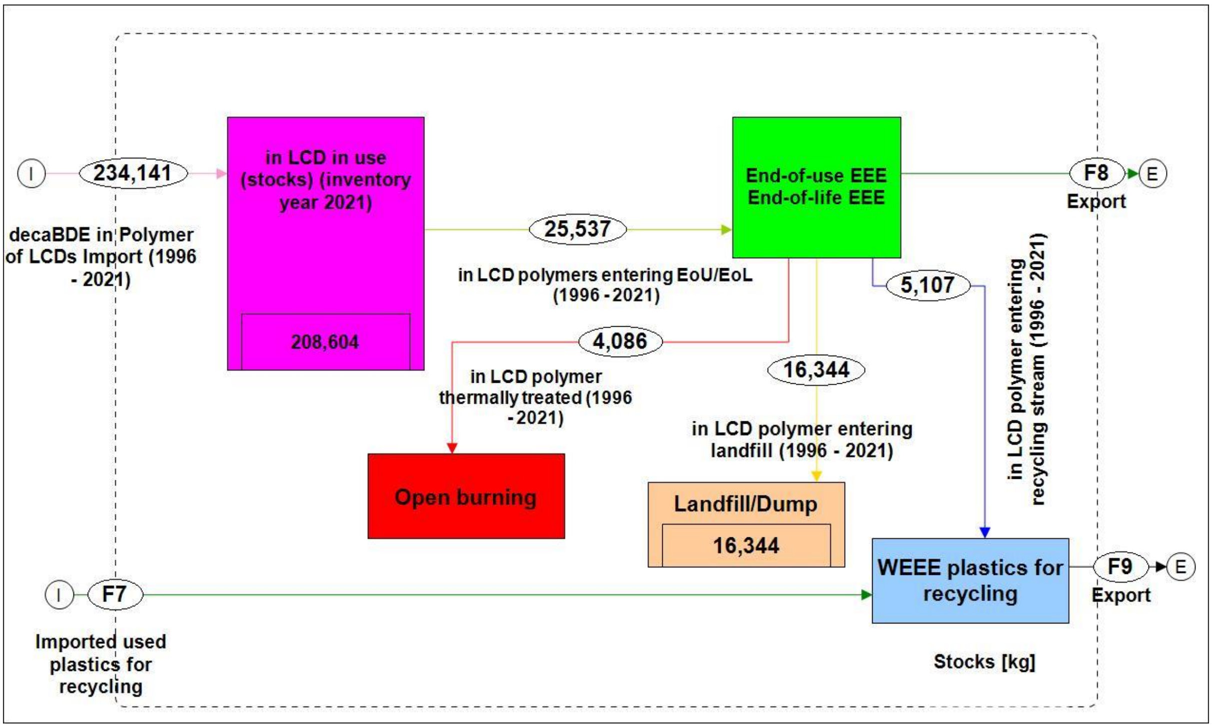

Figure C-6: Substance flow of decaBDE (tonnes) in LCD polymers in Nigeria for flows considering 2000-2021 and the stock in the inventory year 2021

5 STEP 4 Managing and evaluating data and STEP 5 Report writing

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.

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.

The data have been reviewed by different experts and comments have been considered in this compilation which also revealed to calculation mistake mentioned above.

Furthermore the data of the Tier III inventory were partly presented at international conferences and have been compiled in a peer reviewed scientific publication (Sindiku et al. 2012[20]; Babayemi et al. 2018[6]) for assessment and discussion. In this process the approach and data were be reviewed by the POPs research community and subjected to their evaluation.

5.2 Gaps and uncertainties and further improvement

The following gaps and uncertainties

- The updated inventory is based on the baseline inventory from 2012[5] and import data based on the UN Comtrade database up to 2021. The former assessment has shown that the data of Nigeria in the Comtrade database had some uncertainties in the past with high fluctuation for data before 2010. These data were already cleaned in the 2012 inventory and for the data 2011 to 2019 the data seemed more robust and consistent.

[20] Sindiku et al. (2014) PBDEs 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

- The impact factors for SCCPs, MCCPs, dechlorane plus and HBCD are based on two dataset from WEEE studies in Switzerland (Taverna et al 2017[11]; dechlorane plus and HBCD) and a study of the Norwegian Environment Agency[21] (SCCPs and MCCPs). For these compounds no measurements in EEE/WEEE have been conducted in Africa or other developing countries/regions.
- Currently no detailed assessment of the flows/releases of POPs and other CoCs from EEE/WEEE into the environment and related human exposure in the different life cycle stages have been performed. While several studies have shown pollution at e-waste sites and landfills e.g. chicken eggs, milk, vegetables and soil (Oloruntoba et al. 2019[22]; 2022[23]), more systematic quantitative assessment of these flows should be conducted.
- A larger uncertainty exists for the percent distribution of end-of-life treatments and on the recycling. This will need further assessment in particular considering that currently larger activities on improving WEEE management take place. Therefore this is a task within the NIP implementation. This includes the status of recycling of WEEE plastic in Nigeria and the products produced. Also the amount of reused EEE (electronics from the end-of-use phase refurbished/sold again in the second hand marked) should be better assessed including the service life of different equipment which is needed for a more robust MFA/SFAs.
- Other CoCs were not assessed in the current inventory. Since high levels of PFRs were detected an African e-waste sites[24] and extreme high levels in leachates from African landfills[25] there are urgent need to include PFRs in EEE/WEEE inventories but impact factors are missing. Also heavy metals and PFAS have been detected at African e-waste recycling sites and should be included in future assessments.

5.3 STEP 5 Inventory report and managing of the data

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.

The baseline EEE/WEEE inventory have been published in a report (Ogungbuyi et al. 2012)[5] and the report is available on the BRS website. The updated POP data in this study are captured in this case study and can be used for update of the NIP.

[21] Norwegian Environment Agency (2021) Environmental Pollutants in Post-Consumer Plastics. Fraunhofer and Rambol for the Norwegian Environment Agency, Case Number M-2059|2021.

[22] Oloruntoba K, Sindiku O, Osibanjo O, Balan S, Weber R (2019) Polybrominated diphenyl ethers (PBDEs) in chicken eggs and cow milk around municipal dumpsites in Abuja, Nigeria. Ecotoxicol. Environ. Saf. 179, 282-289, https://doi.org/10.1016/j.ecoenv.2019.04.045

[23] Oloruntoba K, Sindiku O, Osibanjo O, Weber R (2022) Polybrominated diphenyl ethers (PBDEs) concentrations in soil, sediment and water samples around electronic wastes dumpsites in Lagos, Nigeria, Emerg. Contam. 8, 206-215, https://doi.org/10.1016/j.emcon.2022.03.003

[24] Eze CT, Otitoloju AA, Eze OO, et al. (2023) West African e-waste-soil assessed with a battery of cell-based bioassays. Sci Total Environ.; 856, 159068. doi:10.1016/j.scitotenv.2022.159068

[25] Sibiya, I., Poma, G., Cuykx, M., Covaci, A., Adegbenro, P. D., Okonkwo, J. (2019). Targeted and non-target screening of persistent organic pollutants and organophosphorus flame retardants in leachate and sediment from landfill sites in Gauteng Province, South Africa. Science of the total environment, 653, 1231-1239.