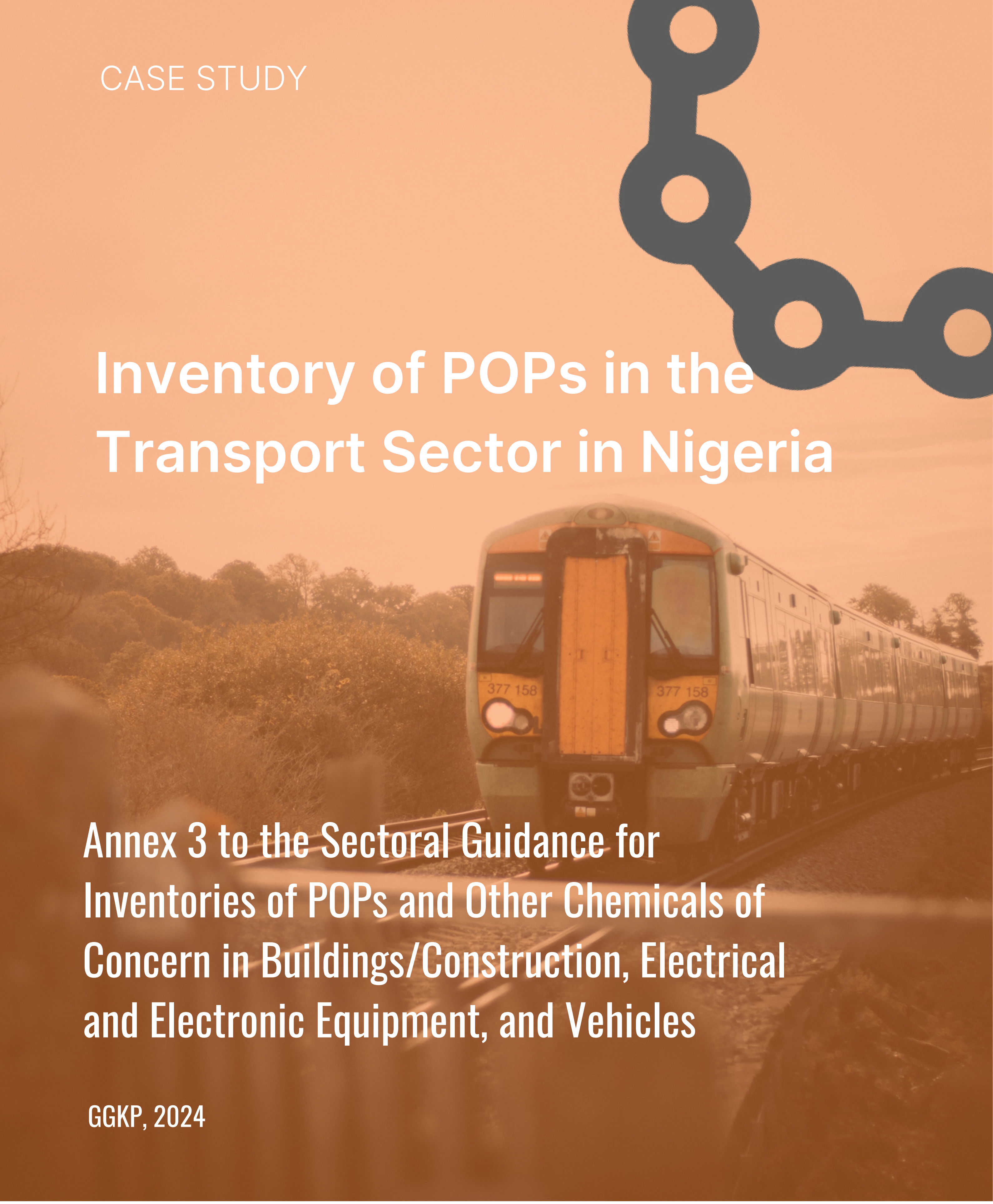

CASE STUDY

Inventory of POPs in the Transport Sector in Nigeria

Annex 3 to the Sectoral Guidance for Inventories of POPs and Other Chemicals of Concern in Buildings/Construction, Electrical and Electronic Equipment, and Vehicles

GGKP, 2024

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Annex 3: Inventory of POPs in the Transport Sector in Nigeria[1]

[1] This case study is an Annex to the GGKP. Sectoral guidance for inventories of POPs and other chemicals of concern in buildings/ construction, electrical and electronic equipment, and vehicles. Geneva, 2024.

Tables

Figures

1 Introduction

Lagos saw the arrival of Nigeria's first two motor vehicles in 1902. By 1937, this number had increased to 7,507 nationwide, with Lagos launching its first public transport system in 1915 (Agbo, 2011).[2] Today, cars and minibuses are the most common forms of commuting in Nigeria while train, subway and public bus systems have remained undeveloped.

Imported vehicles and transportation fleets, such as planes and ships, contain large metal resources (e.g. ferrous metals, copper and aluminium), as well as a wide range of persistent organic pollutants (POPs) (e.g. c-PentaBDE, decaBDE, HBCD, SCCPs, PFOA, UV-328 DP) and candidate POPs (MCCP) and other chemicals of concern that require proper management at end-of-life (see POPs sectoral guidance Chapter 4,[3] and the PBDE and DP BAT/BEP guidance[4]).

A significant number of used vehicles with low environmental performance have been exported from industrial countries to low- and middle-income countries, where they are often used for extended periods until they break down (PBDE Inventory Guidance[5]). As a result, many vehicles imported since the 1970s remain in operation in developing countries.

An initial inventory for PBDEs listed in 2009 was established for the Nigerian transport sector in 2012.[6] This case study develops an inventory of various POPs present in Nigeria's transport sector, including a dynamic substance flow analysis of major POPs, following the PBDE inventory guidance[5] and methods applied in Japan.[7]

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

In this first step, the objectives and scope of the inventory were defined and a work plan was developed (see, for example, Section 3.1. of the PBDE Inventory Guidance[5]). The POP inventory for the transport sector is expected to cover the following life cycle stages:

- Vehicles imported/exported in the inventory year
- Import data from previous years as a basis for estimating/evaluating stocks and service life
- Currently registered vehicles (vehicles in use of consumers/corporates)
- End-of-life vehicles entering the waste stream
- Export of vehicles
- Total amount of plastic and other polymers from end-of-life vehicles recycled
- Polymers of end-of-life vehicles disposed of in the past

For the 2012 initial inventory, the inception workshop on new POPs, held in March 2012 in Nigeria, formed a working group to develop the first PBDE inventory in the transport sector.[6] This group, led by transport sector expert Professor Cornelius Agbo, included members from ministries of environment and transport, waste management authorities, customs, industrial

[2] Agbo, C.O.A. (2011) A critical evaluation of motor vehicle manufacturing in Nigeria. Nigerian J of Technology 30 (1), 8-16.
[3] GGKP (2024) Sectoral guidance for inventories of POPs and other chemicals of concern in buildings/ construction, electrical and electronic equipment, and vehicles.
[4] UNEP (2024) Guidance on best available techniques and best environmental practices relevant to the polybrominated diphenyl ethers (PBDEs) and Dechlorane Plus (DP) listed under the Stockholm Convention on Persistent Organic Pollutants.
[5] UNEP (2021) Draft guidance on preparing inventories of polybrominated diphenyl ethers (PBDEs) listed under the Stockholm Convention on Persistent Organic Pollutants. Secretariat of the Basel, Rotterdam and Stockholm Conventions.
[6] Babayemi J.O, Osibanjo O, Sindiku O, Weber R (2018) Inventory and substance flow analysis of polybrominated diphenyl ethers in the Nigerian transport sector – contribution for end-of-life vehicles policy and management. Environ Sci Pollut Res Int. 25, 31793-31928.
[7] Liu H, Yano J, Kajiwara N, Sakai S. (2019) Dynamic stock, flow, and emissions of brominated flame retardants for vehicles in Japan. Journal of Cleaner Production 232, 910–924.

sectors, the Basel Convention Regional Centre (Prof. Osibanjo) and academic institutes (Dr. Joshua Babayemi, formerly Ibadan University).

As no prior inventory existed, this effort also served as Nigeria's first transport sector inventory. With support from the stakeholder group, Professor Agbo and Dr. Babayemi compiled the information in cooperation with the Ministry of Environment and other key stakeholders to gather the information. Additionally, in partnership with Prof. Johann Fellner of the Technical University Vienna, they used the free STAN software[8] to calculate material and substance flows,[6] both for the initial PBDE inventory and for the current update. An international consultant also supported the team.

In 2022, Associate Professor Joshua Babayemi (now at the University of Medical Sciences, Ondo, Nigeria), who compiled the first inventory, was tasked with organizing the update. This leveraged the institutional knowledge gained during the initial inventory, particularly in gathering information and establishing a material flow analysis (MFA)/substance flow analysis (SFA). The Technical University of Vienna was involved in the effort to provide capacity building in dynamic MFA/SFA, which can be used, for example, to predict the amount of end-of-life vehicles (ELVs) and related POPs or resources in the future for policy advice.

A work plan for POP inventory update was developed in July 2022, targeting completion by December 2022, including a visit to the Technical University in Vienna. The sectoral inventory focused on cars, buses and trucks, as they make up a large portion of Nigeria's transport sector and contain the largest volume of POPs. Planes, trains and ships were not considered for the inventory since all three categories are small and impact factors are not provided in the guidance, though some initial information on these sectors was gathered through a literature review.

3 Step 2: Choosing the inventory methodology

The POP inventory was developed following the five steps inventory approach provided by the POP-PBDE Inventory Guidance[5] (Sections 3 and 7) and Figure 1 of this sectoral POP guidance.[3]

In the **Tier 1 phase (Section 4.1)**, an assessment of the availability of updated data from the former used main database (Lagos State motor vehicle statistics) was conducted. One new stakeholder was discovered in this survey: the Nigeria National Automotive Design and Development Council (NADDC), which did not exist at the time of the first inventory.

For the main inventory, a **Tier 2 assessment (Section 4.2)**, establishing an inventory by gathering, screening and evaluating available data and compiling data, was carried out for this study.

As part of **Tier 3**, a dynamic MFA/SFA was developed (see **Section 4.3** below). With the available time and budget, no additional measurements of POPs in the transport sector were conducted, but impact factors were given by the sectoral guidance. t was also concluded that data should be sourced in a similar manner as in the first inventory at Lagos State, where the largest share of vehicles enter Nigeria and which has robust data and information, including the origin of the vehicle.

Since different POPs have been used in different periods, it was key to get information on the age distribution of the vehicles imported, in current use and in end of life. In the planning of the inventory, it was also concluded that the data should be subjected to an MFA/SFA to visualize

[8] Institute of Water Quality and Resource Management, http://iwr.tuwien.ac.at/resources/downloads/stan.html

the material and substance flows as a basis for policymaking and waste management strategies.

A work plan was developed to compile data. The main responsibility for compiling the data and for the dynamic MFA/SFA was given to Associate Professor Babayemi.

4 Step 3: Collecting and compiling the data

4.1 Tier 1 Preliminary assessment

The initial assessment relies on collecting such "low-hanging fruit" as existing information, desk studies, literature searches and interviews. The priority is to get an overview of the present and historical use of the chemical and its life cycle in the country for refining the scope and planning the inventory process:

- Production
- Uses
- Waste management and potential recycling of materials containing the chemical
- Waste storage/disposal (end-of-life vehicle management, recycling/spare parts)
- Understanding the life cycle of POP and the potential for emissions

Most of these stages had been assessed for PBDEs in vehicles in Nigeria during the development of the first inventory in 2012[6] and were simply updated. However, a new finding in the initial assessment was that in the end-of-life of vehicles, many spare parts are removed from vehicles and that part of the polymer containing spare parts might contain POPs. Therefore, for this updated inventory, spare parts were also considered, but not assessed in depth due to time constraints. It is important to note that PBDEs in spare parts are exempt.

This updated transport sector inventory also aimed to assess multiple POPs in vehicles, not just PBDEs. The use and presence of other POPs in vehicles (DP, HBCD, PFOS, PFOA, PFHxS SCCPs, UV-328 and the POP-candidate MCCP) need to be evaluated. The new sectoral guidance for the inventory of POPs[3] and relevant references were reviewed to determine if the suggested impact factors were appropriate for Nigerian vehicles and to identify when these POPs were used and likely present.

4.2 Tier 2 Inventory – Inventory based on available and estimated data

4.2.1 Methodology for data collection

The evaluation of available and relevant national data of the transport sector was conducted by using the approach of the PBDE Inventory Guidance[5] covering PBDEs listed in 2009 and decaBDE listed in 2017, with the available data identified and by extrapolating some data to fill gaps.

The sectoral POP guidance[3] was studied for impact factors for other selected POPs (DP, HBCD, PFOA, PFOS and SCCP) and other POP candidate (MCCP). Due to the high impact factor of organophosphorous flame retardants (OPFRs) in vehicles and their high release from African landfills (Sibiya et al. 2019),[9] it was decided that a preliminary estimation of OPFRs in vehicles should also be included. Basic information was compiled for the transport sector on the following (UNEP 2021a):[5]

- Registered vehicles (cars, busses and trucks) between 1980-2020; in use and their age distribution to assess the production periods (e.g. for decaBDE use period 1975 to 2017).
- National statistics on the number of imported vehicles in the past 19 years (1988-2020).

[9] 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

- Vehicles imported for the inventory year and for the years with relevant vehicle imports as a base for estimating total stocks, including the total amount of vehicles having entered end of life; national data and UN Comtrade Database.
- The origin of imported vehicles and related age of vehicles (e.g. for c-PentaBDE vehicles produced before 2005 from US/North America).
- Production/assembly of vehicles in Nigeria.
- End-of-life vehicles in the inventory year and those having already reached end-of-life.
- Treatment and management of end-of-life vehicles including management of plastic from end-of-life vehicles.
- Vehicle spare parts containing decaBDE (see Table 2 of sectoral POP inventory guidance[3]) – production, import, sales of exempted parts.
- Data from Lagos State motor vehicle statistics 2009-2020.
- International trade statistics (http://unstats.un.org/unsd/comtrade).
- Available literature and peer-reviewed paper on Nigerian transport (see respective sections below).

Total imported vehicles

The total number of motor vehicles (cars, buses and trucks) imported/put on the market between 1980 and 2020 in Nigeria were 17,553,599 (Figure A-1).

An unusually high vehicle import was reported for 1999 (Figure A-1). This spike was due to a government-mandated deadline for registering all vehicles, leading to many previously unregistered vehicles being recorded for the first time. As a result, most of these vehicles were already in operation prior to 1999. The lack of significant imports in the 1990s was due to lax import and registration practices. A second peak in registration was observed in 2002 and was driven by favourable government policies on used vehicle imports following the start of democratic rule in Nigeria. (Abam and Unachukwu, 2009).[10]

Table A-1. Total vehicles imported to Nigeria from 1980 to 2020 (See also Figure A-1 for time trend)

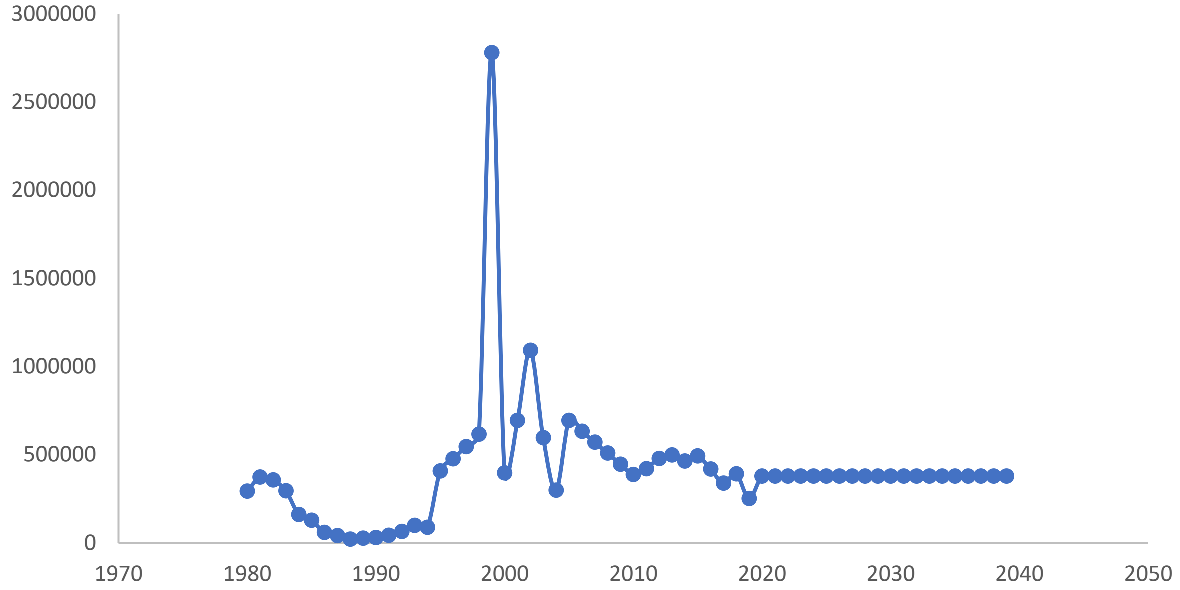
Vehicle type	Cars	Trucks	Buses
Number	12,962,823	299,270	4,291,506

Distribution of the different vehicle types

The distribution of the different types of vehicles imported was established as follows: of motor vehicles registered in Nigeria, 73.8% were cars, 24.4% buses and 1.7% trucks.[11]

10 Abam F.I. and Unachukwu G.O. (2009). Vehicular Emissions and Air Quality Standards in Nigeria. European Journal of Scientific Research, 34 (4): 550-560.
11 Abam, F.I., Unachukwu, G.O. (2009). Vehicular emission and air quality standards in Nigeria. European Journal of Scientific Research, 34 (4): 550-560.

Figure A-1. Total motor vehicles imported/put on the market (1980-2020) and estimated future imported vehicles from 2020 to 2040 for modelling of the dynamic material and substance flow analysis



Information on current transport fleet and total amount of vehicles having entered end-of-life

For this preliminary inventory, relatively good data were available from the registration of vehicles in Nigeria and international statistics such as per capita use of vehicles.[12]. Based on this data, in total 13 million vehicles were registered/in use in 2020. This also correlated with the reported per capita use of vehicles in Nigeria.

No particular export of vehicles from Nigeria has been recorded.

Table A-2. Total vehicles in current use in Nigeria (inventory year 2020)

Vehicle type	Cars	Trucks	Buses	Total
Amount	9,620,000	260,000	3,120,000	13,000,000

Ratio of old and new vehicles in imports

From the available statistical data of imported cars to Lagos, the ratio of imported new cars to imported used cars was 40%:60% (ca. 60% used imported). This ratio was used to also estimate the distribution of buses/trucks. This information is needed for the age distribution of cars; Nigeria only allows the import of cars younger than 15 years.

Information on regional distribution

For some POP calculations in vehicles, the origin of vehicles is relevant (in particular for c-PentaBDE; see below). The data from Lagos State motor vehicle statistics shows that the origin of imported vehicles are registered, including the origin of import. A large share of total vehicles in Nigeria are registered here and therefore this distribution was also used for the rest of the vehicles in Nigeria. Based on the national data, vehicles have mainly been imported from Asia (69%) and Europe (12%) and to some extent from North America (7%), and the remaining from other regions. This distribution was considered where regional distribution was needed for the calculation.

Service life of vehicles

[12] https://en.wikipedia.org/wiki/List_of_countries_by_vehicles_per_capita and references there.

In a developing country like Nigeria, economic factors prevent most vehicle owners from frequently replacing their cars, leading to vehicles being repaired and refurbished repeatedly until they become non-functional. Low labour and operational costs also contribute to the trend. During expert consultations for the first inventory, the service life of vehicles in use and stockpiled with reuse was estimated at 30 years for new cars and 25 years for imported second-hand cars. This was confirmed by a dynamic substance flow analysis (see Tier 3 assessment) where a service life of 30 years aligned with the total vehicle import of 17.5 million vehicles between 1980 to 2020 and the current usage of 13 million vehicles. Estimating vehicles reaching end-of-life is essential for planning waste and resource management of this material flow.

Since 2012, Nigerian legislation only allows the import of used cars less than 15 years old. This means cars produced in and before 2004 – potentially containing PBDEs – are no longer permitted for import. As a result, the current law indirectly restricts the import of vehicles that may contain PBDEs listed 2009.[13]

Exports of vehicles

The UN Comtrade data were also assessed for exports of vehicles. The information did not indicate a relevant export and the quantities were partly in "kg" and for most years "no quantity". Therefore, it was concluded that no relevant export of vehicles takes place from Nigeria.

Reuse and recycling of polymers from end-of-life vehicles

Data on the reuse and recycling of polymers were highlighted as a gap in the 2012 inventory. It also became clear that the spare part market, including many parts containing polymers such as car seats, is an important business in Nigeria and contributes to the extension of vehicle service life and the service life of individual spare parts. It was estimated that at least 20% of polymer parts of a vehicle are going to the second-hand market.

4.2.2 Inventory of PBDEs listed in 2009 and decaBDE in vehicles in Nigeria

PBDEs are the most relevant POPs in vehicles, historically used as flame retardants in plastics, textiles and polyurethane foam.

Factors needed for PBDE calculation for vehicles include the:

- amount of vehicles for the different sectors (cars, buses and trucks)
- amount of vehicles in the different life cycle stages (import, in use, end-of-life)
- origins of manufacturers of vehicles
- age distribution of vehicles to consider the different impact factor
- impact factors for the different vehicle types (estimated contents of PBDEs in respective vehicle types are given by the PBDE Inventory Guidance).[5]

Based on global data from PBDEs in shredder residues and recalculated average of PBDE content of individual cars (see PBDE Inventory Guidance), the POP-PBDE content is:[5]

- 80 g decaBDE for vehicles produced until 2004 for all regions; except for the US, with relevant use of c-PentaBDE,[14] use of 40 g decaBDE and 40 g c-PentaBDE in the average car[5,15] can be assumed
- 20 g decaBDE for vehicles produced from 2005 to 2017
- 0 g decaBDE/PBDEs for vehicles produced from 2017 onwards (if no exemption for decaBDE is made)

[13] However, some vehicles are illegally imported in particular via neighbouring countries. These illegal imports might also contain POP-PBDEs. The share of these illegal imports needs further assessment.
[14] Commercial-PentaBDE consist of the listed tetraBDE, pentaBDE, hexaBDE and minor heptaBDE (UNEP 2021[5]).
[15] It is estimated that 85,000 tonnes of c-PentaBDE were used in the United States with 36% in transport, 60% in furniture and a 4% residual in other articles (Alcock et al., 2003; UNEP, 2010b).

According to the Stockholm Convention PBDE Inventory Guidance, based on this practical approach, the following formula can be used to estimate the PBDE amount in vehicles:

PBDEs in vehicles =
Vehicles (1970-2004) x 80 g decaBDE*/vehicle + Vehicles (2005-2017) x 20 g/vehicle

**For the US, it is assumed that the content is 40 g decaBDE and 40 g c-PentaBDE[15] included in average vehicles before 2005.*

The estimate can be adjusted for larger or smaller cars or buses as appropriate.[5] The inventory guidance stresses that if robust PBDE data are available for a country/region, then these data can be used instead of the suggested PBDE impact factors.[5]

Based on the assessment of total imports (Figure A-1 and Table A-3) and the decaBDE impact factors, the total amount of decaBDE in the 17,553,599 vehicles imported from 1980 to 2020 was 1,484 tonnes. This calculation is based on the assessment of the age of vehicles having different impact factors[5] (See Table A-3 and Table A-4). Furthermore, it was considered that a share was new cars and another share was imported used cars with an age of up to 15 years.

The current vehicle fleet of 13,000,000 vehicles in current use (in 2020) still contained 1,098 tonnes (74%) of the imported decaBDE in vehicles. In the last 40 years (1980-2020), 386 tonnes of decaBDE contained in vehicles entered end-of-life (see Table A-5).

Table A-3. Number of used and new vehicles imported to Nigeria from different regions since 1980 and PBDE impact factors selected for this study based on PBDE inventory guidance

Region of origin	Vehicles	Registration/put on market							
		2005-2020				1980-2004			
		Number of vehicles	DecaBDE per vehicle	Penta BDE per vehicle	HBCD	Number of Vehicles	DecaBDE per vehicle	Penta BDE per vehicle	HBCD
Non-US	New cars	2,276,829	20 g		3	2,616,492	80g		2
	Used cars	3,415,245	80 g		3	3,924,739	80g		2
	New trucks	74,874	20 g		3	37,378	80g		2
	Used trucks	112,311	80 g		6	56,068	80g		2
	New buses	486,596	40 g		6	1,083,975	160g		4
	Used buses	729,895	160 g		6	1,625,963	160g		4
US	New cars	94,867	20 g		3	196,940	40g	40g	2
	Used cars	142,301	40 g	40 g	3	295,410	40g	40g	2
	New trucks	4,642	20 g		2	2,813	40g	40g	2
	Used trucks	6,964	40 g	40 g	2	4,220	40g	40g	2
	New buses	64,441	40 g		4	81,589	80g	80g	4
	Used buses	96,663	80 g	80 g	4	122,384	80g	80g	4
Total		7,505,628				10,047,971			

** Total number of vehicles (1980-2020) is 17,553,599, of which approximately 13,000,000 (74%) are in current use (in the year 2020).*

Table A-4. Amount of decaBDE in individual vehicle type and age in Nigeria imported from 1980 to 2020

Region of origin	Vehicles	Registration/put on market					
		2005-2020			1980-2004		
		Number of vehicles	DecaBDE per vehicle	Amount of decaBDE (kg)	Number of Vehicles	DecaBDE per vehicle	Amount of decaBDE (kg)
Non-US	New cars	2,276,829	20g	45,536	2,616,492	80g	209,319

	Used cars	3,415,245	80g	273,219	3,924,739	80g	313,979
	New trucks	74,874	20g	1,497	37,378	80g	2,990
	Used trucks	112,311	80g	8,984	56,068	80g	4,485
	New buses	486,596	40g	19,463	1,083,975	160g	173,436
	Used buses	729,895	160g	116,783	1,625,963	160g	260,154
US	New cars	94,867	20g	1,897	196,940	40g	7,877
	Used cars	142,301	40g	5,692	295,410	40g	11,816
	New trucks	4,642	20g	93	2,813	40g	112
	Used trucks	6,964	40g	279	4,220	40g	169
	New buses	64,441	40g	2,578	81,589	80g	6,527
	Used buses	96,663	80g	7,733	122,384	80g	9,791
Total		7,505,628		483,754	10,047,971		1,000,655

Table A-5. Amount of decaBDE (tonnes) in vehicles in current use and vehicles having entered end-of-life (1980 to 2020) and the related share landfilled, openly burnt, or reused in spare parts

Tonnes	DecaBDE in vehicles in current use (2020)	DecaBDE imported* in vehicles in the inventory year (2020)	DecaBDE in end-of-life vehicles (2020)	DecaBDE reused in spare parts (1980 - 2020) (20% of EoL)	DecaBDE in dump sites from transport sector (1980-2020) (64% of EoL)	DecaBDE in open burning from transport sector (1980-2020) (16% of EoL)
DecaBDE	1,098		386	77	247	62

4.2.2.1 Estimation of c-PentaBDE in vehicles considering import distribution for the different regions

The production of c-PentaBDE (containing tetraBDE and pentaBDE) stopped in 2004 and therefore only cars produced before 2005 might contain c-PentaBDE. However, only a smaller part of the cars produced between 1975 to 2005 worldwide have been treated with c-PentaBDE. The use of c-PentaBDE depends on the national/regional legislations and production/use patterns. More than 90% of c-PentaBDE has been used in the US/North America (PBDE Inventory Guidances[5,];Abbasi et al. 2019[16]). Only a share of the cars in the US have been treated with c-PentaBDE[17] and also decaBDE and organophosphorus flame retardants (OPFRs) have been used in US/North America since the 1980s. Therefore, only 40 g c-PentaBDE (corresponding to approx. 25% of US cars produced before 2005 were treated with c-PentaBDE) (POP-PBDE Inventory Guidance[5] Chapter 5).

The amount of c-PentaBDE (PBDEs listed in 2009) contained in the 1,113,234 vehicles originating from the US (import 1980-2020) is calculated to be 50 tonnes (Table A-6). In the inventory year 2020, out of the 13 million motor vehicles in current use, 520,000 (4%) originated from the US. This implies 593,234 motor vehicles (53%) originating from the US

[16] UNEP (2015) Revised draft guidance for the inventory of polybrominated diphenyl ethers under the Stockholm Convention. UNEP/POPS/COP.7/INF/27.
[17] According to the use pattern of c-PentaBDE, approx. 200 million cars produced in the US/North America from 1975 to 2004 could have been contaminated with c-PentaBDE.

have reached end-of-life, and this contained 26.5 tonnes c-PentaBDE, while 23.5 tonnes (47%) are contained in motor vehicles in current use (Table A-7).

Table A-6. Amount of c-PentaBDE in individual vehicle type and age in Nigeria imported from 1980 to 2020

Region of origin	Vehicles	Registration/put on market					
		2005-2020			1980-2004		
		Number of vehicles	c-PentaBDE per vehicle	Amount of c-PentaBDE (kg)	Number of Vehicles	c-PentaBDE per vehicle	Amount of c-PentaBDE (kg)
Non-US	New cars	2,276,829			2,616,492		
	Used cars	3,415,245			3,924,739		
	New trucks	74,874			37,378		
	Used trucks	112,311			56,068		
	New buses	486,596			1,083,975		
	Used buses	729,895			1,625,963		
US	New cars	94,867			196,940	40 g	7,878
	Used cars	142,301	40 g	5,692	295,410	40 g	11,816
	New trucks	4,642			2,813	40 g	113
	Used trucks	6,964	40 g	279	4,220	40 g	169
	New buses	64,441			81,589	80 g	6,527
	Used buses	96,663	80 g	7,733	122,384	80 g	9,791
Total		7,505,628		**13,704**	10,047,971		**36,293**

Table A-7. Amount of c-PentaBDE (tonnes) in vehicles in current use and vehicles having entered end-of-life (1980 to 2020) and the related share landfilled, openly burnt, or reused in spare parts

(tonnes)	c-PentaBDE in vehicles currently in use (2020)	c-PentaBDE in end-of-life vehicles (1980-2020)	c-PentaBDE reused in spare parts (2020)	c-PentaBDE in dump sites from transport sector (1980-2020)	c-PentaBDE in thermally treated from transport sector (1980-2020)
c-PentaBDE	23.5	26.5	5.3	17	4.2

4.2.3 Estimate of HBCD in vehicles in Nigeria

In the Japanese national inventory for PBDE and HBCD in vehicles, an impact factor for HBCD has been determined (3 g HBCD/car) (see Section 4.3.2 of sectoral POP inventory guidance[3]). There are no regional impact factors due to a lack of studies. Therefore the suggested impact factor was used for the estimate of HBCD in vehicles in Nigeria. It was also considered that the HBCD use in vehicles was stopped in 2013 (see Sectoral guidance Section 4.3.2[3]) and therefore vehicles produced from 2014 on do not contain HBCD.

Total amount of HBCD in the 17,553,599 motor vehicles imported 1980-2020 was 61 tonnes. From these, the current registered 13,000,000 vehicles contain an estimated 45 tonnes (year 2020) and 16 tonnes HBCD were contained in vehicles in EoL from 1980 to 2020 (see Table A-8 and Table A-9).

The sectoral POP inventory guidance[3] also informs that refrigerator trucks frequently contain XPS as insulation where HBCD have been used at least until 2013. However there were no data/information on the amount of such trucks in Nigeria.

Table A-8. Amount of HBCD in individual vehicle type and age in Nigeria imported 1980 to 2020

Region of origin	Vehicles	Registration/ Put on market	
		Used vehicles in 2014-2020	New and used vehicles in 1980-2013

		Number of Vehicles	HBCD (g/car)	Amount of HBCD (kg)	Number of Vehicles	HBCD (g/car)	Amount of HBCD (kg)
	Cars	1,425,996	3	4,278	10,586,166	3	31,758
	Trucks	49,501	3	149	212,964	3	639
	Buses	165,080	6	990	3,905,958	6	23,436
Total		1,640,577		5,417	14,705,088		55,833

Table A-9. Estimated amount of HBCD (tonnes) in vehicles in current use and in vehicles having entered end-of-life (1980 to 2020) and the related HBCD landfilled, openly burnt, or reused in spare parts

(tonnes)	POP imported in vehicles (1980-2020)	HBCD in vehicles currently in use (2020) (74%)	HBCD in end-of-life vehicles (1980-2020)	HBCD reused in spare parts (1980-2020) (20% of EoL)	HBCD in dump sites from transport sector (1980-2020) (64% of EoL)	HBCD in open burning from transport sector (1980-2020) (16% of EoL)
HBCD	61	45	16	3	10	3

4.2.4 Estimate of SCCPs and MCCP in vehicles in Nigeria

Measurements of automotive shredder fraction (ASR) in Japan and Europe suggest an impact factor for SCCPs of 2.4 g/car (see Section 4.2.2 of sectoral POP Inventory Guidance[3]) and an impact factor for MCCP (MCCP is in POPRC evaluation) of 50g/car (see Section 4.4.3 of sectoral POP inventory guidance[3]). These impact factors were used for a first estimate of CPs in the vehicles in Nigeria. SCCP and MCCP are still produced in high amount and SCCP has exemptions for uses in relevant applications in vehicles (e.g. PVC, rubber, lubricants). Further, it was assumed that SCCP and MCCP were used mainly in vehicles from 2000 on where production has strongly increased in China and India with a large share of MCCPs/SCCPs used as plasticizer in PVC (Chen et al. 2021[18]; Li et al. 2023[19]). More data of SCCPs/MCCPs in vehicles with respect to age/region is needed and when more robust data are available, the MFA/SFA can be updated.

The total number of vehicles produced in 2000-2020 imported to Nigeria was 10,491,407. These are estimated to contain 30 tonnes SCCP and 633 tonnes of MCCP (Table A-10). Since the lifetime of motor vehicles in Nigeria ranges between 25-35 years, it is assumed that almost all of these vehicles are still in current use, and only a negligible amount of these cars ended in end-of-life up to 2020.

Table A-10. Amount of SCCPs/MCCPs in the Nigerian transport sector in 2020 (in kg)

Vehicles	Registration/put on market (2000-2020)				
	Number of vehicles	SCCP		MCCP	
		SCCP/vehicle (g)	Amount of SCCP (t)	MCCP/vehicle (g)	Amount of MCCP (t)
Cars	8,099,244	2.4	19.4	50	405
Trucks	225,985	2.4	0.54	50	11,3
Buses	2,166,178	4.8	10.4	100	217
Total	**10,491,407**		**30.4**		**633**

4.2.5 PFOS, PFOA and PFHxS in vehicles in Nigeria

Measurements of automotive shredder fraction (ASR) in Europe suggest an impact factor of extractable PFOA of 15mg/car (see Section 4.2.3 of sectoral POP Inventory Guidance[3]).

[18] Chen C, Chen A, Li L, Peng W, Weber R, Liu J. (2021) Distribution and Emission Estimation of SCCP/MCCP in Chinese Products through Detection-Based Mass Balancing. Environ. Sci. Technol. 55, 7335–7343.
[19] Li et al. (2023). What do we know about the production and release of persistent organic pollutants in the global environment?. Environmental Science: Advances. DOI: 10.1039/d2va00145d.

Extractable PFOS and PFHxS in these ASRs had an average concentration of 3mg/car and 0.2 mg/car.[3] These impact factors were used for the estimate of the vehicles in Nigeria. Since PFOA is still produced and has an exemption for treating textiles and use in fluoropolymers, PFOA and related substances might still be present in new vehicles, it is considered for the current inventory and dynamic MFA/SFA that the use started in 1980 and will further be used until 2025.

For PFOS, the POPRC concluded in 2012 that PFOS use is likely stopped and not needed in textiles, upholstery and carpets and can be removed as exemption. Therefore, it is considered that vehicles produced between 1980 to 2012 contain PFOS and PFHxS-related substances (considered at the detected concentration an unintentional co-pollutant of PFOS) and that vehicles produced from 2013 on do not contain PFOS or PFHxS-related substances.

The total amount of extractable POP-PFAS in motor vehicles in Nigeria (1980-2020) was estimated to 328 kg (PFOA), 66 kg (PFOS) and 4 kg (PFHxS).

The life cycle stage distribution of extractable PFOS, PFOA and PFHxS is given in Table A-12 below. While 243 kg of extractable PFOA is still present in vehicles in use, 54 kg of PFOA has been dumped in end-of-life vehicles in recent years.

The guidance stressed that these POP-PFAS amounts are only the extractable PFOS/PFOA and that the amount of side chain fluoropolymer, for example, on seat textiles, could be much higher but were not extracted in the study (methanol extraction without oxidation) from which the impact factors have been developed.[3]

Table A-11. Amount of extractable PFOA, PFOS and PFHxS (kg) in the Nigerian transport sector in 2020

Vehicles	Registration/put on market						
	1980-2020						
	Number of vehicles	PFOA		PFOS		PFHxS	
		PFOA/ vehicle (mg)	Amount of PFOA (kg)	PFOS/ vehicle (mg)	Amount of PFOS (kg)	PFHxS/ vehicle (mg)	Amount of PFHxS (kg)
Cars	12,962,823	15	194	3	39	0.2	3
Trucks	299,270	15	45	3	1	0.2	0.2
Buses	4,291,506	30	129	6	26	0.4	1.7
Total	17,553,599		328		66		4

Table A-12. Estimated amount of POP-PFAS (kg) in vehicles in current use and vehicles having entered end-of-life (1980 to 2020) and the related PFAS landfilled, openly burnt, or reused in spare parts

(in kg)	Extractable POP-PFAS imported 1980-2020	Extractable POP-PFAS in vehicles in current use (2020) (74%)	Extractable POP-PFAS in end-of-life vehicles (2020) (26%)	Extractable POP-PFAS in reused parts (1980-2020)* (20% of EoL)	Extractable POP-PFAS in dump sites from transport sector (1980-2020) (64% of EoL)	Extractable POP-PFAS openly burnt transport sector (1980-2020) (16% of EoL)
PFOA	328	243	85	17	54	14
PFOS	66	49	17	3	11	3
PFHxS	4	3	1	0.2	0.64	0.16

4.2.6 Halogenated organophosphorus flame retardants

Halogenated organophosphorus flame retardants (OPFRs) are major flame retardants present in vehicles that are not POPs, but have certain toxic properties and are found in high levels of African landfill leachate (Sibiya et al. 2019).[20] There are only initial measurements of OPFRs in automotive shredder fraction (ASR) in Japan, which suggest an impact factor for OPFRs of 10 to 100g/car (see Section 4.2.3 of sectoral guidance[3]).

As a tentative impact factor, 50 g of OPFR for cars and 150 g for (mini)buses were selected for this inventory of the Nigerian transport sector. Since chlorinated OPFRs are still produced and used in vehicles in textiles and PUR foam, they are still used in new vehicles. OPFRs have largely substituted BFRs in vehicles starting in the 1990s. Therefore, it is considered that 1,166 tonnes of OPFRs were imported to Nigeria in 15,789,445 vehicles from 1990 to 2020 (Table A-13). In the inventory year 2020, the 13 million vehicles in current use are estimated to contain 956 tonnes of OPFRs in vehicles in current use (2020), while 163 tonnes of OPFRs have entered end-of-life in the past 30 years (Table A-14).

Table A-13. Amount of OPFR (t) in the Nigerian transport sector in 2020

Vehicles	Registration/put on market (1990-2020)		
	Number of vehicles	PFRs /vehicle (g)	Amount of PFRs (tonnes)
Cars	11,727,915	50	586
Trucks	281,628	50	14
Buses	3,779,902	150	566
Total	**15,789,445**		**1,166**

Table A-14. Amount of OPFR[21]* (t) in the Nigerian transport sector in 2020

	OPFR imported* in vehicles (1990-2020)	OPFR in vehicles in current use (2020)	OPFR in end-of-life vehicles (1990-2020)	POP in spare parts (2020)**	POP in dump sites and landfills (1980-2020)**
OPFRs	903	**740**	**163**	*25*	*104*

4.2.7 Inventory summary of POPs amount in the transport sector

Table A-15 below summarizes the amount of brominated POPs and SCCPs/MCCPs in vehicles in Nigeria in the life cycle: total former imports, current use/stock and in end-of-life, including spare parts. This is complemented by Table A-12 for PFOS, PFOA and PFHxS (Table A-12) and OPFRs (Table A-14).

The largest amount of POPs in vehicles stems from decaBDE where approximately 1,100 tonnes are still in the vehicle fleet. A high amount of MCCP (633 tonnes), which is currently in the POPRC, is also present in vehicles and is still increasing due to continuous production.

A special concern is the large quantities of POPs from end-of-life vehicles in Nigerian dumpsites (Table A-15) since PBDE contamination around these sites has been found (Oloruntoba et al. 2019).[23] High releases of chlorinated OPFRs were also recently detected in leachates from African landfills with associated risks for the surrounding areas.[20,24]

[20] 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.

[21] Halogenated OPFRs are not POPs but different OPFs have certain toxic properties.

[23] 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.

[24] PBDEs and OPFRs are also included in plastic in electronics and polymers in buildings and related waste and have therefore several sources in landfills.

Table A-15. POPs in the Nigerian transport sector present in the life cycle stages in 2020* (in tonnes)

(in tonnes)	POP imported* in vehicles (1980-2020)	POPs in vehicles currently in use in inventory year (2020)	POP in end-of-life vehicles (1980 to 2020)	POP in spare parts (2020)**	POP in dump sites and landfills (1980-2020)**
c-PentaBDE	51	**23.5**	**26.5**	*1*	*17*
decaBDE	1,484	**1,098**	**386**	*19*	*247*
HBCD	44	**33**	**11**	*0.6*	*7*
SCCP***	30	**30**	**-**	-	-
MCCP***	633	**633**	**-**	-	-

** POPs in the imported vehicles are also included in the inventory of "current transport" and "end-of-life"*

*** Please note: POPs in spare parts and the POPs in landfills are part of POPs in end-of-life 1980 to 2020.*

**** Since a vehicle's lifetime in Nigeria is 25-35 years, it is assumed that vehicles produced since 2000, where major use of SCCPs/MCCPs in PVC started, are in current use and none in end-of-life.*

4.2.8 Total polymers in the transport sector

Transport is a major use of plastic and other polymers. While approximately 7% of all plastic is used in the transport sector, the long service life results in the share of the transport of total plastic increasing to 15%.[25]

Plastic use in transport is increasing. While cars produced in the 1970s contained approximately 50 kg of plastic/polymers, this increased to 160 kg by 2008. Meanwhile, average cars contain approximately 200 kg of plastic/polymers, including approximately 25 kg of synthetic textiles (Szeteiova 2008[26]; American Chemical Council 2016[27]). While the PBDE Inventory Guidance suggests an average plastic content of 200 kg for cars, for the Nigerian inventory only 150kg since many vehicles older than 2010 are still in operation. For (mini) buses, 400 kg polymers are considered and for trucks 200 kg. Based on these impact factors and the total import of vehicles, a total of 3.7 million tonnes of plastic and other polymers have been imported to Nigeria. From these, 2.7 million tonnes of plastic is in the current transport sector while 1 million tonnes entered end-of-life.

4.2.9 Other chemicals of concern in the transport sector

In this first sectoral inventory of POPs in transport in Nigeria, other chemicals of concern present in vehicles were not assessed, such as heavy metals (e.g. lead, mercury), ODS/GHGs (CFCs, HFCs), PFRs or phthalates (see Section 4.5 of sectoral inventory guidance). However, contacts were made to the Minamata, Basel and Rotterdam focal points to inform on the sectoral POP inventory[3] and on interest in cooperating to a larger sectoral inventory with chemicals of concern in other multilateral environmental agreements. In the Minamata initial assessment, mercury in the transport sector was not addressed. Considering the relevant amount of vehicles produced before 2004 (UNEP 2019), it was concluded that in the next assessment, vehicles should be included in the mercury inventory.

Furthermore, it was concluded that lead and selected other metals of concern in the transport sector should be assessed also considering the option of better resource recovery of metals. A contact with the Montreal Protocol team was also established to see if an inventory of F-gas

[25] Wang, C., Liu, Y., Chen, W. Q., Zhu, B., Qu, S., & Xu, M. (2021). Critical review of global plastics stock and flow data. Journal of Industrial Ecology, 25(5), 1300-1317.
[26] Szeteiova. (2008). Automotive materials plastics in automotive markets today.
[27] American Chemistry Council. 2016. Plastics and Polymer Composites in Light Vehicles.

as ODS or GHG stocks in the transport sector (air conditioners; refrigerator trucks and lorries) have been developed. Since this was not the case, it was concluded that in the refining of the POPs inventory in the transport sector, cooperation with the Montreal Protocol team should develop an F-gas inventory in vehicles.

4.2.10 Assessment of POPs in other transport sectors in Nigeria (planes and trains)

Within the information-gathering phase, preliminary information on other transport sectors was compiled. Currently, Nigeria does not have an operating airline – Air Nigeria stopped operating its 11 planes in 2012. Nigerian Airways stopped operation in 2003, but is currently planning a potential relaunch. Flights in and out of Nigeria are operated by international airlines.

The Nigerian Railway Corporation has 480 passenger coaches and less than 50% of the coaches are in serviceable condition.[28] These coaches likely contain flame retarded seats and might also contain POPs. Further inventory assessment is needed, in particular for the coaches no longer operational and their end-of-life management.

4.3 Tier 3 Material and substance flow analysis of POPs and POP-containing materials from the transport sector

For compiling the data in a visualized form and to gain an overview of the life cycle of materials containing POPs in the transport sector, an MFA of these materials and SFA of the relevant POPs (PBDEs, SCCP/MCCP, HBCD, PFOA/PFOS/PFHxS) have been performed.

4.3.1 Material and substance flow analysis

An MFA systematically shows bulk material flows through society in a comprehensive way. The underlying principle of an 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/substances starts at a source (e.g. production or import) and ends at a sink (e.g. export or landfill). An SFA is a specific type of MFA used for tracing the flow of a selected chemical (or group of substances) through a defined system.[29,30]
A key aim of an MFA is to visualize the complex material/substance flow of a selected system (in this case the flow of POP-PBDEs in transport in Nigeria) in a simplified but correct manner to serve, for example, as a tool/support for decision- making in waste management. In the current study, the system boundary is the country of Nigeria. The goods included in this study are main vehicle categories (cars, buses and trucks). The substances considered in the substance flow are POPs. The system, therefore, comprises the materials in transport in Nigeria and focuses on the listed POPs in transport. The stocks and flows in the system include importation, use/reuse, end-of-life (recycling, thermal treatment, landfill/dump) and export.

4.3.2 Overview of flows and stocks of POPs in the transport sector Nigeria

The strength of the MFA/SFA is the visualization of complex material and substance flows. The University of Vienna provides material flow software (STAN) as open source,[31] which was already used for the first PBDE inventory in Nigeria.[6] However, for the current MFA/SFA, it was decided to use a dynamic MFA/SFA to develop predictions of the POPs in vehicle flows in Nigeria for providing information for the coming years on POPs in end-of-life vehicles in Nigeria, which can be used for planning their management, particularly the existing plastic/polymer fraction.

In a dynamic material flow, the future flow of vehicles can be modelled based on the current vehicle fleet where the total amount of vehicles (for Nigeria 13,000,000 registered vehicles) and the age distribution are known. The average service life for new cars was assumed to be

[28] https://en.wikipedia.org/wiki/Nigerian_Railway_Corporation
[29] Baccini P, Brunner PH (2012) Metabolism of the Anthroposphere: Analysis, evaluation, design. 2nd edition, MIT Press, Cambridge US.
[30] Brunner PH, Rechberger H (2003) Practical Handbook of Material Flow Analysis. Lewis Publishers.
[31] http://iwr.tuwien.ac.at/resources/downloads/stan.html

35 years. The average age of newly registered/imported used cars was assumed to be 10 years. Therefore, the average service life of registered used cars was assumed to be 25 years from the time of registration. The stock and the amount of the investigated substances in end-of-life vehicles were determined by applying a Weibull lifetime function (form factor 5 for new cars, 3 for used cars) to the input of the according substance.

Figure A-2. Substance flow and stocks of decaBDE in Nigeria's transport sector (1980-2020); the stocks are for the inventory year 2020 and the flows are the total volume from 1980-2020

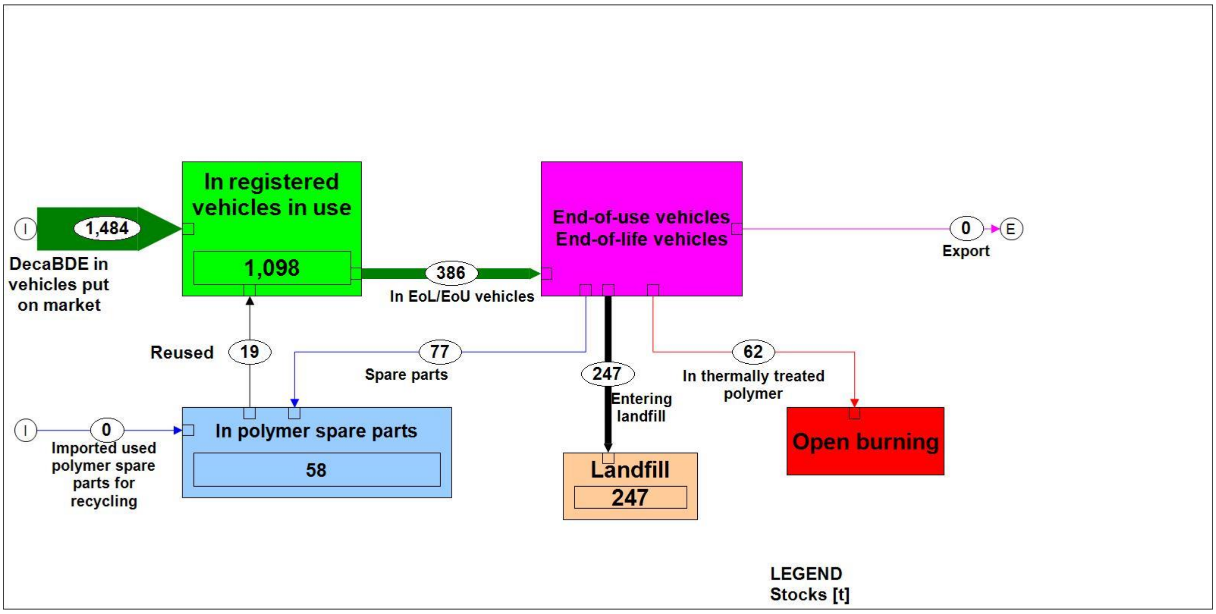


Figure A-3. Estimated amount of decaBDE in end-of-life vehicles in Nigeria for respective years (1981-2040) based on dynamic material and substance flow analysis of registered vehicles in Nigeria

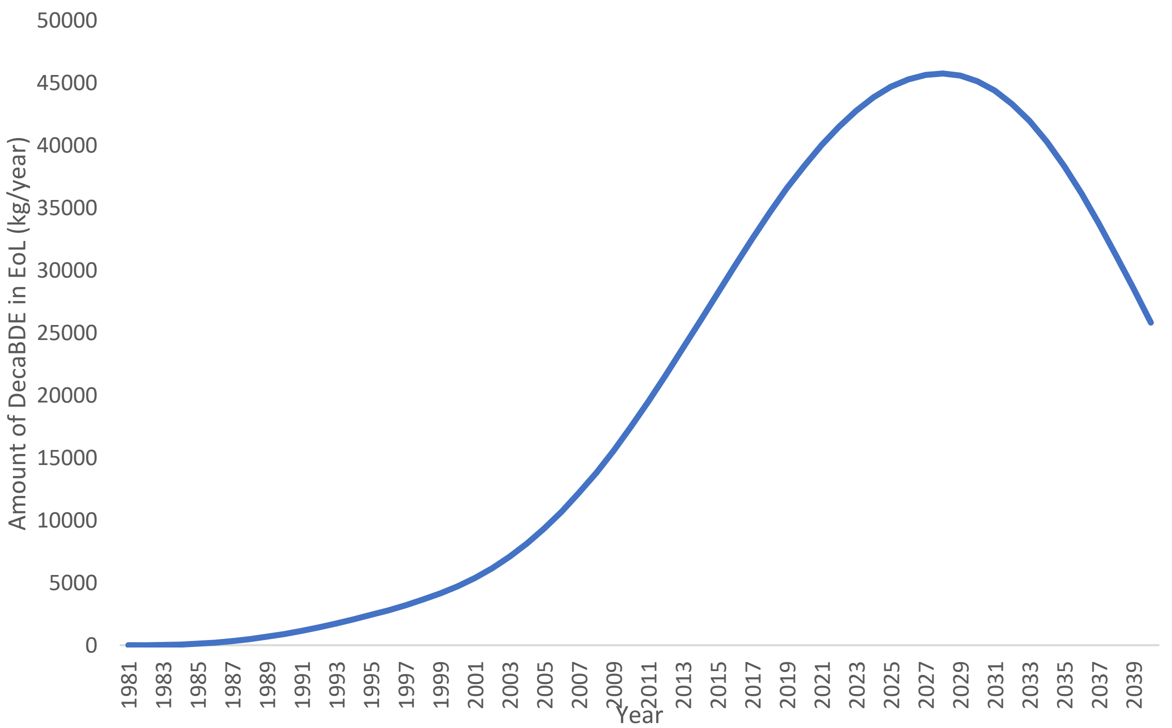


Figure A-4. Substance flow and stocks of c-PentaBDE (including tetraBDE, pentaBDE) in the transport sector in Nigeria (1980-2020); the stocks are for the inventory year 2020 and the flows are the total volume from 1980-2020

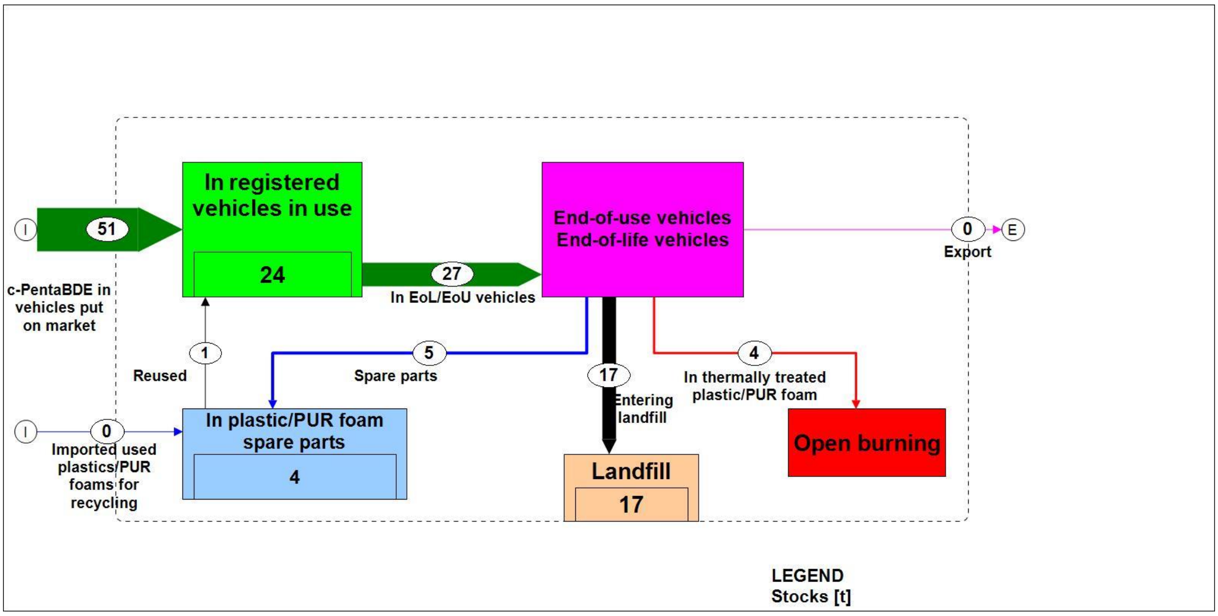


Figure A-5. Estimated amount of c-PentaBDE (tetraBDE/pentaBDE) in end-of-life vehicles in Nigeria for respective years (1981-2040) based on dynamic material and substance flow analysis of registered vehicles in Nigeria

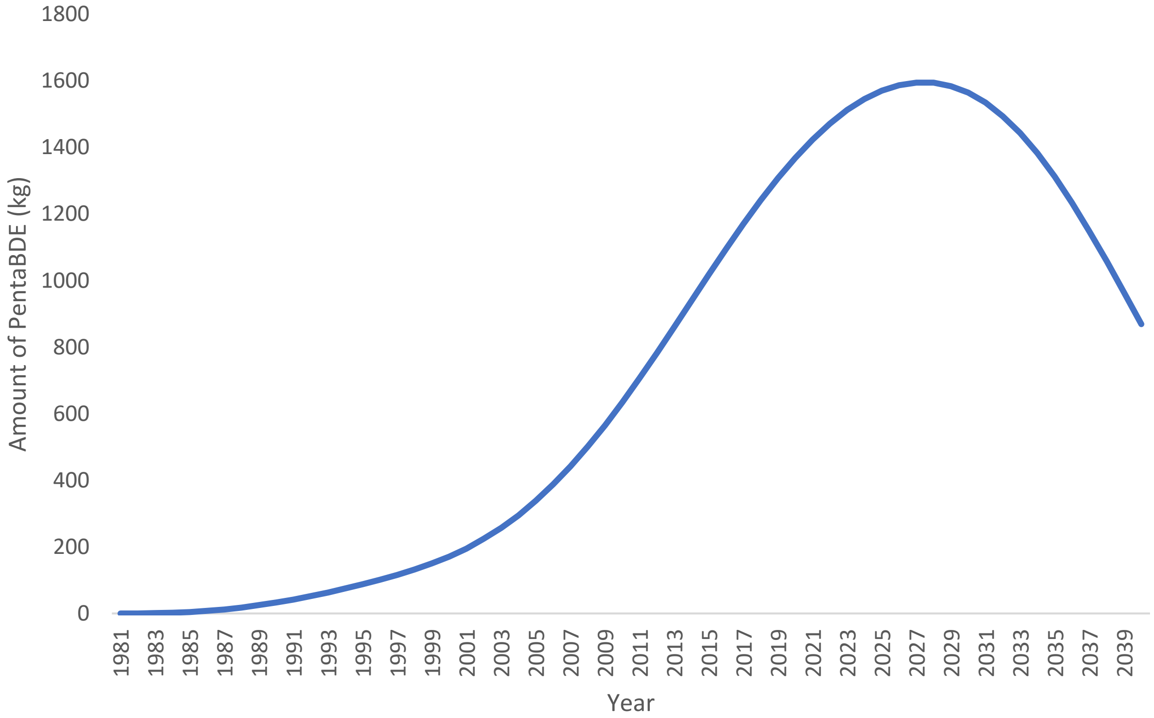


Figure A-6. Substance flow and stocks of HBCD in Nigeria's transport sector (1980-2020); the stocks are for the inventory year 2020 and the flows are the total volume from 1980-2020

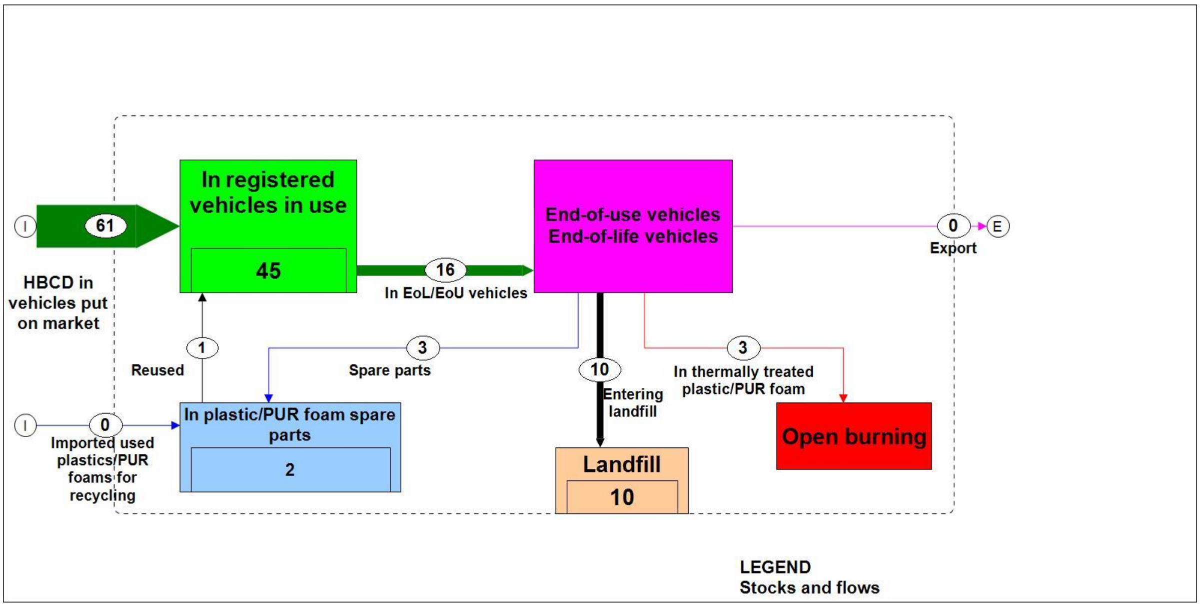


Figure A-7. Estimated amount of HBCD in end-of-life vehicles in Nigeria for respective years (1981-2040) based on dynamic material and substance flow analysis of registered vehicles in Nigeria

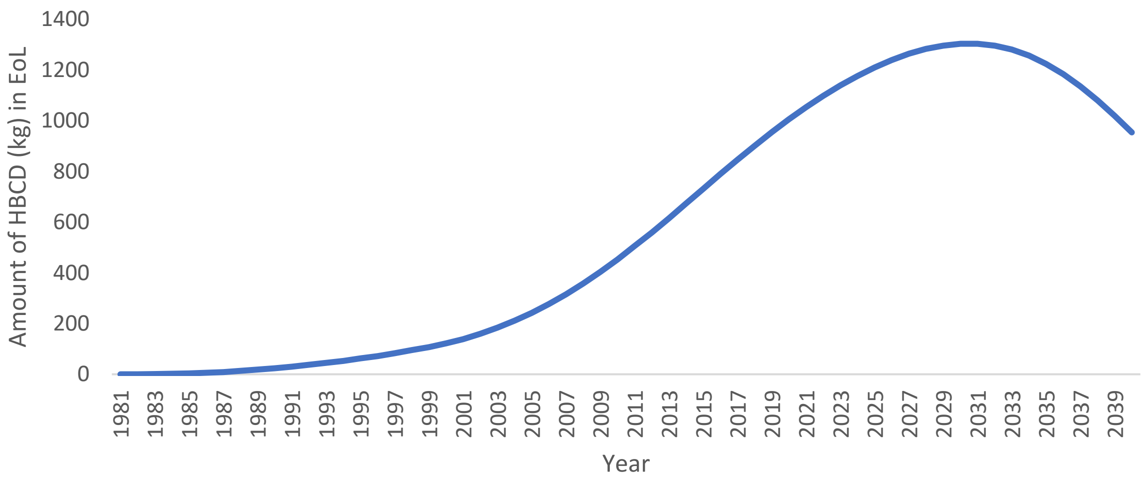
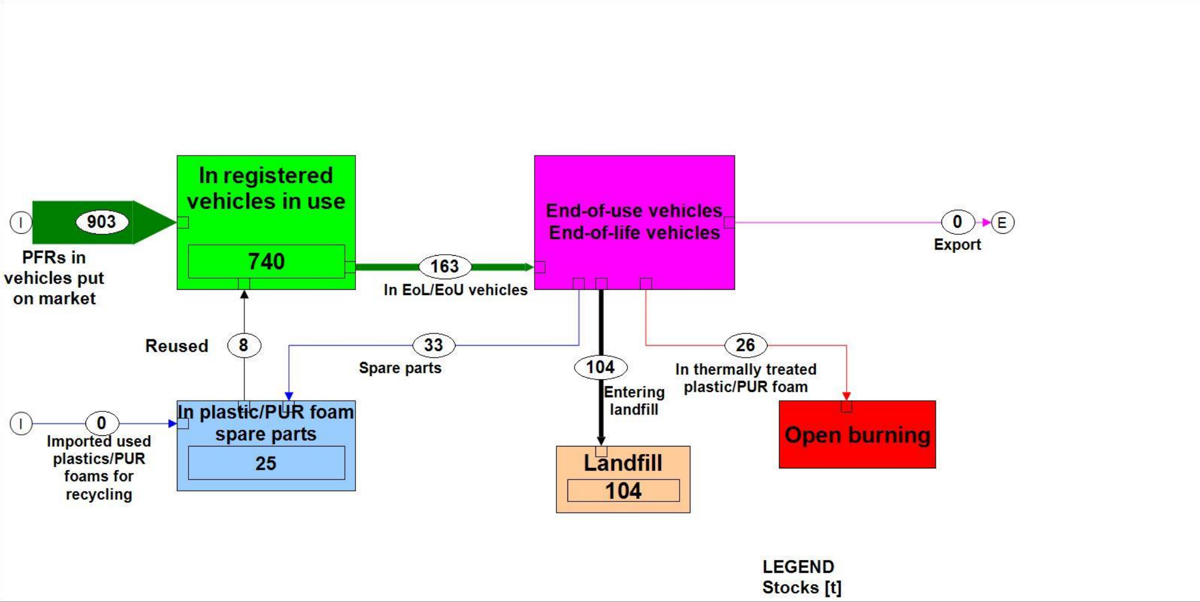


Figure A-8. Substance flow and stocks of OPFR in Nigeria's transport sector (1980-2020); the stocks are for the inventory year 2020 and the flows are the total volume from 1980-2020.



5 Step 4: Managing and evaluating data

The current sectoral inventory of POPs in vehicles can be considered a preliminary inventory since it includes a range of uncertainties and assumptions (see below). The inventory considers the life cycle of the vehicles in Nigerian – import, current use/stock, end-of-life treatment and disposal.

5.1 Evaluation of data and further improvement of the data

In this inventory step, data are assessed for completeness and plausibility, possibly including the comparison with data from other countries in the region (See Guidance on QA/QC[32]). The information gathered was assessed by the transport expert and director of the Basel Convention Regional Centre and approved for use in the preliminary inventory compilation (Tier 2). The Nigerian transport expert supplied data from his research results on Nigerian road safety.

Within the short time available for the current inventory, this step has only been done to some extent. Data gaps in this study have (partly) been filled by extrapolation of data. This was done, for example, for the import data from different world regions and the amount of vehicles in end-of-life (see above).

5.2 Uncertainties and improvements for developing a more robust inventory

The current preliminary inventory contains a range of uncertainties and assumptions:

- In the current inventory ships, airplanes and trains were not included. However, the air fleet and trains in Nigeria are minor and therefore do not make a relevant contribution.
- There are no official statistics on end-of-life vehicles. The amount of end-of-life vehicles in the current inventory was therefore estimated from the total amount of vehicles in use and

[32] UNEP (2023) Short Guidance on implementing Quality Assurance and Quality Control (QA/QC) for POPs Inventories Data Validation.

the estimated life span of vehicles. The improvement of this situation will need to wait for the overall development of a vehicle de-registration system in Nigeria.

- A large uncertainty exists for the percent distribution of end-of-life treatments, including the recycling rate based on this preliminary inventory of data for general waste. This will need further assessment efforts for an in-depth inventory, particularly considering that currently, larger plans for polymer recycling exist in Nigeria.
- The distribution of originating regions of imported vehicles is currently based on data from Lagos vehicle statistics (covering more than 50% of total import) and is extrapolated to the other regions of the country.
- The POP impact factors are based on a few measurements and might be refined in the future. Many of the data are from Japan and Europe; impact factors from China, Korea and North and South America. Therefore, an in-depth inventory could be improved by screening and analysis of POPs (PBDEs, HBCD, SCCPs/MCCPs, Dechlorane Plus, UV-328, and POP-PFAS) in vehicles.

5.3 Managing the data

The gathered general inventory data for Nigeria's transport sector have been compiled:

- vehicles in the different life cycle stages
- plastics and other polymers in the transport sector potentially contaminated by POP.
- major POPs additives (PBDEs, HBCD, Dechlorane Plus, SCCP/MCCPs) present in the vehicles

as a material/substance flow analysis with predictions of POPs in end-of-life vehicles until 2040. As can be seen by e.g. Figure A-3 and Figure A-7, the presence of POPs in the transport sector and ELVs and related POP release in the transport sector will continue beyond 2040.

Since the data are valuable for the (waste) management of end-of-life vehicles (and prediction of end-of-life vehicles), they will be shared with departments responsible for waste and resource management in Nigeria, including the Ministry of Environment and other responsible ministries. The data will then be integrated into and managed within a database maintained by the government body responsible for waste and resource management.

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

This SFA of POPs in the transport sector describes the flow from import, use/stocks until the end-of-life including the recycling stage. There are currently considerable uncertainties with 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 needs to be better assessed and should become a priority within the action plan of a National Implementation Plan (NIP). Within this assessment, the options and limitations of POPs separation and management will be assessed.

Currently, no assessment of the flows/releases of POPs and other CoCs from vehicles into the environment and towards human exposure in the different life cycle stages has been performed. This is a future task and might also be included in the action plan. A detailed assessment, particularly for different end-of-life and recycling options, needs to be carried out focusing on best practices that can be implemented in Nigeria in the future.

6 Step 5: Inventory report

The current case study of the transport sector has been established for this sectoral guidance. The data can be included in the inventory reports for the individual POPs for the update of the Nigerian NIP of the Stockholm Convention.