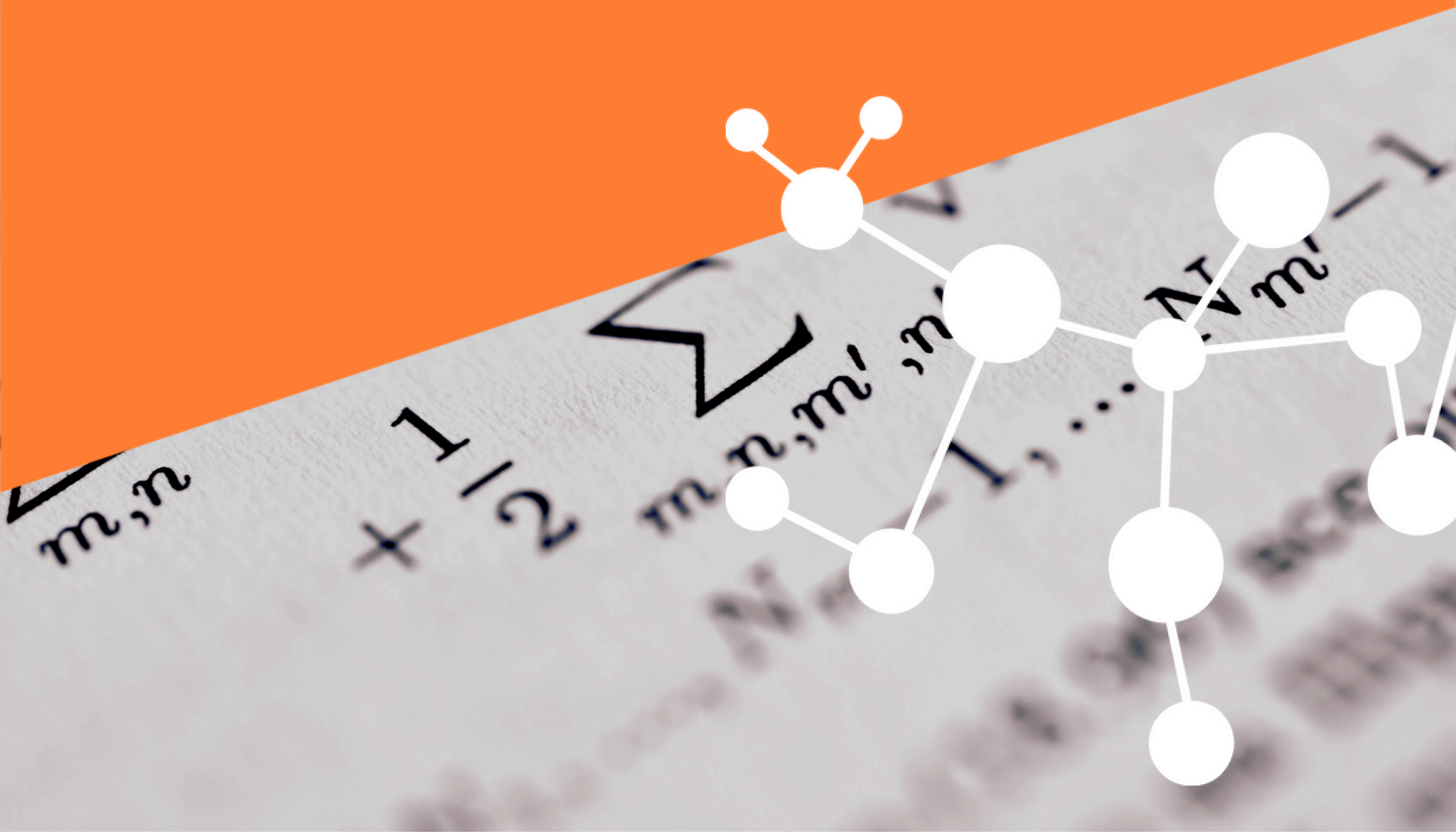
GUIDANCE

Short Guidance on Implementing Quality Assurance and Quality Control (QA/QC) for POPs Inventories Data Validation

GGKP, 2024



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Abbreviations and Acronyms

AFFF	Aqueous film forming foam
BFR	Brominated flame retardant
BRS	Basel, Rotterdam and Stockholm conventions
CAS	Chemical Abstracts Service
c-DecaBDE	Commercial Decabromodiphenyl ether
c-OctaBDE	Commercial Octabromodiphenyl ether
c-PentaBDE	Commercial Pentabromodiphenyl ether
CP	Chlorinated paraffin
CRT	Cathode-ray tube
DDT	Dichlorodiphenyltrichloroethane
decaBDE; BDE-209	Decabromodiphenyl ether
EEE	Electrical and electronic equipment
ELV	End-of-life vehicle
EPS	Expanded polystyrene
GHG	Greenhouse gas
HBB	Hexabromobiphenyl
HBCD(D)	Hexabromocyclododecane
HCBD	Hexachlorobutadiene
HCH	Hexachlorocyclohexane
heptaBDE	Heptabromodiphenyl ether
hexaBDE	Hexabromodiphenyl ether
HS codes	Harmonized System codes
MCCPs	Medium-chain chlorinated paraffins
MFA/SFA	Material and substance flow analysis
NFP	National Focal Point
NIP	National Implementation Plan
NPC	National Project Coordinator
ODS	Ozone-depleting substance
PCBs	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PCNs	Polychlorinated naphthalenes
PCP	Pentachlorophenol and its salts and esters
PeCB	Pentachlorobenzene
pentaBDE	Pentabromodiphenyl ether
PFASs	Per- and polyfluorinated alkylated substances
PFHxS	Perfluorohexane sulfonic acid
PFOA	Perfluorooctanoic acid; perfluorooctanoate
PFOS	Perfluorooctane sulfonic acid; perfluorooctane sulfonate
PFOSF	Perfluorooctane sulfonyl fluoride
POPs	Persistent Organic Pollutants
POPRC	Persistent Organic Pollutants Review Committee

PVC	Polyvinyl chloride
QA	Quality assurance
QC	Quality control
SCCPs	Short-chain chlorinated paraffins
t	Tonnes; metric tons
tetraBDE	Tetrabromodiphenyl ether
UNEP	United Nations Environmental Programme
UNITAR	United Nations Institute for Training and Research
UNU	United Nations University
WEEE	Waste electrical and electronic equipment
XPS	Extruded polystyrene

1 Introduction and Approach

1.1 Background on POPs inventory data and the need for QA/QC

The main objective of developing inventories for persistent organic pollutants (POPs) is to acquire information on managing POPs for developing and reviewing National Implementation Plans (NIPs) and for meeting the various information requirements of the Stockholm Convention (e.g., Article 15 reporting). Inventories for POPs need to provide enough information for the identification of national priorities outlined in the NIP, or for the development of elimination projects. Therefore, accurate and reliable data on the quantities of POPs that are produced, used, stockpiled and generated as waste in the country are imperative (UNEP 2020).

For the development of robust and validated inventories of POPs, it is necessary to carry out an integrated evaluation step of the gathered data. Therefore, within the five-step approach suggested by the POPs inventory guidance (Figure 1), Step 4 is on "managing and evaluating the data (Figure 1; for details see UNEP 2020).

In Step 4 of the inventory, data should be assessed for completeness and plausibility; some elements of a quality assurance/quality control (QA/QC) system are already briefly mentioned as a first baseline (UNEP 2020). However, no document specifically informs on QA/QC for POPs inventories. For that reason, this document serves as a short guidance on the implementation of a more complete QA/QC system for data generation and validation in POPs inventories.

Figure 1: Five-step approach for the development of POPs inventories (UNEP 2020)

Step 1: Initiating the inventory development process
- Establishing a national inventory team
- Identifying relevant stakeholders
- Defining the scope of the inventory
- Developing a workplan
- Contacting the stakeholders

Step 2: Choosing data collection methodologies
- Indicative method
- Qualitative method
- Quantitative method

Step 3: Collecting and compiling data
- Tier 1: Initial assessment
- Tier II: Main inventory
- Tier III: In-depth inventory

Step 4: Managing and evaluating the data

Step 5: Preparing the inventory report

1.2 QA/QC as good practice

The implementation of a quality assurance/quality control (QA/QC) system and plausibility procedures is recommended as a good practice in the development of POPs inventories to achieve timelines, transparency, consistency (coherence), comparability, completeness (see section 2.3.2), improvement and accuracy (IPCC 2006 and United Nations 2019). Box 1 below provides some definitions of these terms used in this guideline, but countries for developing NIPs may have their own definitions (United Nations 2019). The procedures described in this guidance also serve to drive inventory improvement.

A list of data quality objectives for POPs inventories is compiled in Box 2, which also gives an idea of the practice of QA for POP inventories.

Box 1: Some definitions of QA/QC terms (United Nations 2019)

Coherence: the ability to reliably combine data (and statistics) in different ways and for various uses. Consistency is often used as a synonym for coherence.

Comparability: the extent to which differences in data (or statistics) from different geographical regions/countries, or over time can be attributed to differences between true values of the data (or statistics).

Accuracy: the closeness of estimates to the exact or true values that the data (or statistics) were intended to measure.

Transparency: the terms and conditions of data (or statistics) are available to the public and documentation how the data were generated, and amounts were calculated.

Box 2: List of data quality objectives for POPs inventories

- All major inventory areas are considered to the extent feasible and reasonable (Section 2.3.2) to ensure completeness in the country and consistency and comparability between countries.
- Check the degree to which a set of data of an inventory fulfills requirements to ensure completeness.
- Data are more complete and robust than in the former inventory (comparison with former inventory) to improve accuracy, consistency and comparability.
- Data to be more reliable, consistent, representative, transparent and reproducible (to meet the related quality principles).
- Have clear and traceable sources (and references where appropriate); data should be based on robust national primary data, validated data gathered in the inventory process, or peer-reviewed published data to ensure transparency, accuracy and consistency.
- Material flow analysis and substance flow analysis (MFA/SFA) of imports, stocks and waste are consistent (e.g., see case studies Annexes of Weber and Babayemi 2023) to ensure consistency, transparency, completeness and comparability.
- The quantities of individual POPs have been subjected to plausibility assessment (e.g., compared to global production and use data; Section 2.5) to ensure consistency.
- Own measured data are based on robust QA/QC criteria in the laboratories (see Section 3.3) to improve accuracy.
- Check if the calculation is reproducible and if there are any unusual and unexplained trends noticed for activity data or other parameters across the time series when used to ensure consistency and accuracy and comparability.
- Base decisions to the extent possible on results that are non-controversial within major stakeholders, including experts and research. If there are controversial opinions, then

further information from experts or the research community might help in a science and fact-based decision to ensure transparency, accuracy and consistency.

The QA/QC and plausibility activities should be an integral part of the POPs inventory process. The outcomes of QA/QC and plausibility assessments may result in the reassessment of POPs inventory uncertainty analysis and subsequent improvements of the inventories, the NIP, the reporting under Article 15, and ultimately a better NIP implementation.

The methodology described in this guidance considers other guidance documents that are recommended for further reading:

- United Nations National Quality Assurance Frameworks Manual for Official Statistics including recommendations, the framework and implementation guidance, Department of Economic and Social Affairs Statistics Division, ST/ESA/STAT/SER.M/100 United Nations New York, 2019 (United Nations 2019)
- General guidance on POPs inventory (UNEP 2020)
- Intergovernmental Panel on Climate Change (IPCC) Quality assurance/quality control and verification. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6: QA/QC and Verification (IPCC 2006; and 2019 refinement IPCC 2019)
- Basel Convention Methodological Guide for the development of inventories of hazardous wastes and other wastes under the Basel Convention (UNEP 2016)

This QA/QC guidance also considers the experiences and challenges faced by countries and experts during the development of POPs inventories and NIPs in different countries (UNEP 2018).

1.3 Practical considerations

In practice, inventory teams have limited resources and time. Thus, QA/QC requirements, improved accuracy and reduced uncertainty must be balanced against requirements for timeliness and cost-effectiveness. A good practice system for QA/QC seeks to achieve that balance and to enable continuous improvement of inventory estimates (IPCC 2006).

In terms of the implementation of QA/QC procedures, there should be no difference between confidential and publicly available data; both should carry descriptions of the measurement and calculation procedures and the steps taken to check and verify the values reported. These procedures may be carried out on the confidential data by either the provider of the information or by the inventory team and, in either case, confidential source data should be protected and archived accordingly. However, the QA/QC procedures that are implemented need to remain transparent and their description available for review. The report should contain a description of the relevant QA/QC procedures applied (IPCC 2006).

2 Mechanisms and Elements for QA/QC of POPs and Inventory Data

The following sections provide an overview of the implementation of quality assurance and quality control (QA/QC) procedures for sectoral POPs inventories.

The following are the major elements of a general QA/QC system recommended to be implemented in an inventory for POPs (see Figure 2), which are covered in detail in the following sections (IPCC 2006).

- Responsibilities
- QA/QC plan
- Data quality

- QA and review procedures
- Plausibility assessment
- Documentation and reporting (documentation of how the inventory was calculated and documented proofs for the data)

Figure 2: General QA/QC system (adopted from IPCC 2006)

These elements are recommended for gathering data on POPs considering the inventory guidance documents for individual POPs, the sectoral inventory guidance (GGKP 2024a), the document on production, use and trade of POPs (GGKP 2024b), the guiding methodology for strengthening the collaboration with national statistical offices (GGKP 2024c) and the guidance on monitoring POPs in products and recycling (UNEP 2021a). A QA/QC procedure should be applied routinely to the inventory compilation.

2.1 Responsibilities

The guidance on NIP development suggests that a national lead agency would be designated to take responsibility for setting up the structure and mechanisms to develop, review and update the NIP (UNEP 2017). The frame for QA/QC of NIP data can be discussed after the project coordinating unit and national coordinating committee are established. One option is that one member of the national coordinating committee gets the task of ensuring that a QA/QC frame is established for inventory development and all data generated and included into the NIP and the national reporting. Of particular importance is QA/QC in the development of inventories. Therefore, the responsibility for QA/QC and the frame can also be decided when establishing the POPs inventory team (see UNEP 2020, individual POP inventory guidance documents) and defining roles/responsibilities for QA/QC for data generation for inventory. Within the inventory team, a coordinator can be designated as responsible for the QA/QC process.

The QA/QC coordinator in cooperation with the inventory team should ensure that other organizations involved in the preparation of the inventory are following QA/QC procedures and that appropriate documentation of these activities is available (IPCC 2006). The coordinator and the inventory team are also responsible for ensuring that a QA/QC plan (see Section 2.2) is developed and implemented throughout the whole process of the development of POPs inventories and the NIP and for all the data collected.

2.2 QA/QC plan

A QA/QC plan should be an element from the beginning of inventories and NIP updates through to final reporting. The plan should, in general, outline a clear description of the QA/QC activities that will be implemented for the POP inventories and other data.

The QA/QC plan is an internal document to organize and implement QA/QC activities that ensure the inventory is fit for the purpose and allow improvements. Once developed, it can be referenced and used in subsequent inventory preparation, or modified as appropriate (notably, when changes in processes occur or on advice of independent reviewers).

A key component of a QA/QC plan is the list of data quality objectives (see Box 2), which are considered in the development of the inventory and against which an inventory can be measured in a review (IPCC 2006).

Data quality objectives are concrete targets to be achieved in the inventory preparation. They should be appropriate, and realistic (taking national circumstances into account) and allow for an improvement of the inventory. Where necessary (data gaps) and possible, additional data collection or screening (Tier III) is recommended. In developing countries, such monitoring data might be generated in the region or in South-North or South-South cooperation.

As part of the QA/QC plan, it is a good practice to accommodate procedural changes and feedback of experience (IPCC 2006). Conclusions and lessons learned from previous inventory and reviews need to be used to improve the procedures. Such changes can also concern data quality objectives (see Box 2), and the QA/QC plan itself.

The periodic review and possibly revision of the QA/QC plan is an element to drive the continued inventory improvement. Any specific details of a QA/QC system should be defined in the QA/QC plan and national circumstances should be considered.

In developing and implementing the QA/QC plan, it is useful to refer to generic international standards, such as:

- ISO 9000:2000 Quality management systems – Fundamentals and vocabulary
- ISO 9001:2000 Quality management systems – Requirements
- ISO 9004:2000 Quality management systems – Guidelines for performance improvements
- ISO 10005:1995 Quality management – Guidelines for quality plans
- ISO 10012:2003 Measurement management systems – Requirements for measurement processes and measuring equipment and
- National QA/QC procedures

2.3 Quality control

Quality control (QC) procedures include generic quality checks related to calculations, data processing, completeness, gaps and uncertainties and documentation that apply to inventory. Following QC checks should be used routinely throughout the preparation of the inventory, which are introduced in the following sections:

- Data quality (Section 2.3.1)

- Completeness (Section 2.3.2)
- Amount of POPs versus the amount of POP content in wastes or products (Section 2.3.3)
- Gaps and uncertainties (Section 2.3.7)
- Assessment and description of uncertainties
- Time series (Section 2.3.5)

After the data for the POP inventory are compiled, the data should be evaluated (QC) by relevant national stakeholders and possibly by national or international experts. This can be done within a workshop and sending inventory reports for validation in advance for assessment and feedback at or before the workshop. The results of these QC activities and procedures should be documented in the reporting Step 5 in general POP guidance (UNEP 2020).

2.3.1 Data quality

Data quality objectives for POPs inventories are compiled in Box 2 (see Section 1.2). They should be considered during data collection and when compiling and updating data.

Several different data collection methodologies/Tiers can be selected and used for gathering information for POPs inventories which result in different levels of data quality — i.e., indicative method, qualitative method and quantitative method. For more information on those methodologies, refer to Step 2 of the "General Guidance on POPs Inventory Development" (UNEP 2020). While robust quantitative data have high data quality, they might not be feasible within a given time, available human resources, or resource allocation. The different methodologies may vary depending on the legal framework, resources, and time available for the inventory. The report on production and trade/use data (GGKP 2024b) should be considered when developing and evaluating inventory estimates. They are equally applicable to inventory areas where default values or national data are used as the basis for the estimates.

During the data processing, all the assumptions and conversion factors adopted because of expert judgment, where needed, should be noted/recorded and referenced when the results are presented. Nevertheless, the management of the collected and documented data should meet quality objectives (Box 2 in Section 1.2).

Inconsistent data may be correct and usable, but it may also be wrong due to incorrect/unrealistic testing conditions. If certain data is controversial, but cannot be proved wrong, it may be used to indicate the need for further research to allow the closing of a certain gap needed for coming to a decision. Also, many national statistical organizations have their own procedures for assessing the quality of data independently of what the end use of the data may be. National data should be compared with the previous year's data being evaluated and checked for errors in the data. Moreover, where possible, a comparison check of the national data with independently compiled activity data sources could be helpful.

Where possible, the proof for data should be included in inventory reports and the NIP possibly as Annexes (e.g., material safety data sheet or measurements of firefighting foams proofing the presence of PFOS/PFOA; pictures of labels of PCB transformers, etc.).

2.3.2 Completeness — assessment if all major inventory areas were addressed

The lack of completeness is a check where data are not available either because the inventory area (Table 1) is not yet addressed, data were not available, or a data collection method does not yet exist. Typically, this cause can lead to incomplete conceptualization, which results in bias but can also contribute to random error depending on the situation.

The completeness check for POP inventories assesses:

- If all relevant POPs listed in the Stockholm Convention are covered.
- If all major inventory areas were addressed (Table 1).
- If the coverage of major sectors with multiple POPs (buildings, transport, electrical and electronic equipment EEE and related waste (WEEE); GGKP 2024a) is complete.
- If the synergies with other inventories (e.g. inventories for greenhouse gases (GHG) and ozone-depleting substances (ODS)) addressing the same sectors have been evaluated for already generated data and if inventory activities could be combined to minimize time and resources.
- If the estimates and assumptions are documented and referenced.
- If no wrong information is given and if incomplete information can be filled.
- If appropriate impact or emission factors were selected (e.g., from UNEP toolkit or inventory guidance documents).
- If own impact and emission factors were selected it should be ensured that it is explained how they were selected.
- If all data reporting obligations are covered.
- If the imports with pertinent Harmonized System (HS) codes for imports are evaluated (see GGKP 2024b).

Table 1 indicates major production, import, use, stockpile, and contaminated site areas and their relevance for individual POPs to serve as support for the completeness check. Here the inventory team can see which areas are considered critical regarding POP production and use or POP stockpiles for most countries (see also GGKP 2024b). Health risks of newly listed POPs are described in another document (UNEP 2021a).

If major inventory areas are not included in the inventory, it should be stated:

- if they were not included since they are not present in a country; or
- if they might be present in the country, but that an assessment and data gathering could not be conducted; and
- if further activities are planned or currently conducted to generate inventory data.

While Table 1 gives a first overview, the individual inventory guidance documents should be consulted for details of the individual POPs.

Table 1: List of POPs and priority areas for inventory regarding production, uses, stockpiles, waste and contaminated sites (for details see individual inventory guidance)

POP	**Inventory area**	**Comment**	**Countries/Parties (priority)**
decaBDE	Production	China as last producer	Few (high)
	Import, use	Import and certain production for exempted uses	Some (moderate)
	EEE/WEEE plastic	Major use; impacting plastic recycling	All (high)
	Transport (plastic/textiles)	Major use & waste	All (high)
	Construction plastic	Major use & waste; long service life; largest stock today	All (high)
TetraBDE/ pentaBDE (c-PentaBDE) HexaBDE/ hepaBDE	Production	Stopped 2004 (c-PentaBDE c-OctaBDE)	Few (moderate)
	Import, use	In some products produced before 2004	Some (moderate)
	EEE/WEEE plastic	Major use; impacting plastic recycling	All (moderate)
	Transport (plastic/PUR/textile)	Major use & waste (US before 2004)	All (high)

POP	Inventory area	Comment	Countries/Parties (priority)
(c-OctaBDE)	Furniture (PUR foam)	Major use & waste (US before 2004)	Few (moderate)
	Construction plastic and PUR foam	Major use & waste; long service life; largest stock today	All (moderate)
HBCD	Production	Production stopped 2021	Few
	Insulation foam construction	Major use & waste with long service life	All (high)
	E-waste plastic	Minor use & waste	All (low)
	Textiles	Minor use & waste	All (moderate)
HBB	(EEE; vehicles, construction)	Minor production; stopped 1976	No[1] (low)
PFOS, PFOSF (PFHxS)	Production	All production stopped; (potential stock)	Some (high)
	Firefighting Foam	Still used or in stock in many countries; related contaminated sites	All (high)
	Metal and plastic plating	Still used in many countries	Many (high)
	Insecticide (acceptable purpose)	Used in some South American countries	Few (high)
	Carpet, textiles, paper, leather…	Use stopped; major stock in use	All (high)
	Oil drilling, aviation fluid	Former use	Some (moderate)
	Contaminated sites	Most relevant inventory area	All (high)
PFOA	Production, export	Few countries	Few (high)
	Fluoropolymer production	Few countries; high contamination	Few (high)
	Firefighting foam	Still used/in stock in many countries	All (high)
	Textiles	Use in production in some countries Use & waste in most countries;	All (high) Some (high)
	Semi-conductor production	Use in production and release	Few (high)
	Photolithography; photoresist	Use in production and release	Some (high)
	Fluoropolymer in use	Remaining from production	All (moderate)
	Pesticide containers (USEPA)	Likely used in most countries	All (high)
	Contaminated sites	Countries have contaminated sites from former use	All (high)
SCCP (and MCCP[2])	Production and export	Continue in several countries often in CP mixtures	Some (high)
	Additive in PVC	Major use imported to countries	All (high)
	Additive in rubber	Main use imported to countries	All (high)
	Additive in PUR spray foam	Main use imported to countries	All (high)
	Paints and coatings	Likely used in many countries	All (moderate)
	Lubricants; metal working fluids	Likely used in many countries	All (high)
	Fat liquoring of leather	Likely used in many countries	All (moderate)
PCBs	Transformers and other equipment and waste oil	Large stocks and waste; 2025 stop of use; 2028 ESM of all stocks/wastes	Most (high)
	Open uses (paints, sealants)	Major use in industrial countries	Some (high)
	Contaminated sites	Wide pollution; risk for livestock	All countries
PCNs	Production as intermediate for PFN production	One country registered for exemption	One country
	Unintentional production	In Annex C Part II and III sources	All (low)

[1] The production and major use were in the US 1970 to 1976. Mass poisoning of the population in Michigan happened in 1973 due to unintended use of several hundred kg of HBB as animal feed; WHO (1994) https://undark.org/2017/12/18/pbb-michigan-epigenetics.

[2] MCCPs are currently assessed by the POPRC and meet the Annex D criteria. Same uses as SCCPs.

POP	Inventory area	Comment	Countries/Parties (priority)
	Other uses	Stopped more than 20 years ago	Some (minor)
HCBD	Production/use likely stopped	Use likely stopped	Few (high)
	Unintentional production	Production of chlorinated solvents	Few (high)
	Contaminated sites (include HCB, PeCB, PCN)	(Former) Production sites of chlorinated solvents	Few (high)
POP Pesticides (Annex A)	Stockpiles and waste deposits	No production; remaining stocks	Most (high)
	Use (from stockpiles & waste)	Illegal pesticide	Few (moderate)
	Contaminated sites	Production, storage, use sites	Most (high)
PCP	Wood treatment (exemption)	Major former use; long service life	All (high)
	Leather treatment	Major former use; long service life	All (moderate)
	Contaminated sites past use of PCP (including PCDD/PCDF)	High relevance for most countries from wood treatment,	Some (high)
Lindane	Production	Stopped; potential stockpiles	Few (high)
α-/β-HCH	Contaminated sites	Large waste deposits around former production sites	Few (high) (Vijgen *et al.* 2011; 2022)
Dicofol, Endosulfan	Recent stop of production and use	Remaining stocks might still be traded and used	Few (high)
DDT	Production and formulations	One production left; few formulations	Few (high)
	Use	Exempted use; potential illegal use	Few (high)
	Waste and stockpiles	Former production and use	Many (high)
	Contaminated sites	From former production and use	Many (high)

An additional inventory area for all countries is the assessment of the need of exemptions and the use of alternatives in the exempted uses.

2.3.3 Amount of total POP content versus amount of POP-containing products and wastes

For almost all POPs in products, POP contents represent only a share of the product or the waste. For the data, it is essential to ensure that both amounts are clearly described and distinguished. In the QC check of POP inventories, the data need to be assessed for individual POPs if both data — the amount of the total POP content and the amount of POP-containing products/waste — are described.

This means that, for example, for PCBs, the amount of highly contaminated PCB oils (PCB > 5000 mg/kg)[3] needs to be clearly distinguished in the inventory from PCB-contaminated oil containing less than 500 mg PCB/kg[4]. It also needs to be clearly described if only an indicative chlorine test was conducted or if the data were verified and quantified by measurement (see also Chapter 3), and that the total amount of confirmed equipment containing PCB or PCB-contaminated oil and the amount of equipment potentially containing PCB oils need to be clearly distinguished.

For firefighting foams, the total amount of PFOS and PFOA in aqueous film-forming foam (AFFF), the total amount of foams containing PFOS or PFOA and the total (estimated) amount of PFOS or PFOA in these foams need to be clearly stated.

[3] Most transformers above 5,000 mg/kg are Askarel transformers with PCB content of >400,000 mg/kg.
[4] A transformer with 800 mg/kg can be rescued with one oil exchange and the transformer afterward comes below 50 mg/kg.

Also for PBDEs in EEE/WEEE plastic, the amount of estimated PBDEs in the plastic and the total amount of plastic containing PBDEs should be reported. Considering that all WEEE plastic needs environmentally sound management and the PBDE-containing fractions need to be separated from WEEE plastic, the total amount of WEEE plastic is also valuable information for the overall management of PBDEs (and other POPs) in this plastic and for the overall inventory of plastic in the country.

Units for the amount of POPs in the inventory should use the International System of Units (SI) (tonnes, kg). It is recommended to make a robust check of the correctness of units.

Table 2: Some examples where the total amount of a POP, the amount of POP-containing products, and the total amount of POP-impacted product categories are useful to report

	Total POP content	Total amount of POP-containing product	Total amount of product to be assessed/managed*
PBDEs in EEE/WEEE	Amount of PBDEs in plastic in EEE/WEEE	Amount of plastic containing PBDEs in EEE	All plastic in EEE/WEEE
PBDEs in vehicles	Amount of PBDEs in plastic in vehicles	Amount of PBDE containing plastic in EEE	All polymers in vehicles
HBCD	Amount HBCD in EPS and XPS	Amount of EPS/XPS in buildings and construction	Total amount of EPS and XPS
PCB transformers	Total amount of PCBs in transformers	Total amount of transformer oil contaminated by PCBs above 50 mg/kg	All transformers potentially containing PCBs
SCCPs in PVC	Amount of SCCPs in PVC	Total PVC containing SCCPs	Total PVC potentially containing SCCPs
PFOS/PFOA in AFFF foam	Amount of PFOS/PFOA in AFFF foam	Total firefighting foam containing PFOS or PFOA	Amount AFFF foam suspected to contain PFASs
PFOS/PFOA in carpet	Amount of PFOS/PFOA in carpets	Total carpets amount containing PFOS or PFOA	Amount synthetic carpets suspected to contain PFASs

**While a considerable share of the total products of a category does not contain POPs, it is this entire waste fraction which needs to be managed to separate the POP containing plastic/waste.*

2.3.4 Quality improvement of POPs inventories over time and maintenance of data

When countries update the inventory over time, the data quality normally becomes more robust and reliable with improved experience and can better meet QA/QC criteria. Robust inventories developed over time can be used, for example, planning of waste management and material recovery and recycling and control of POP-impacted wastes as well as the development of time trends for effectiveness evaluation (see Section 2.3.5 Time series). Moreover, updating inventories helps to see trends for future POP generation and allows assessing measures for better management of POP-containing wastes.

Also, the quality of inventories of unintentionally produced POPs normally improves over time since frequently more sources are discovered over time resulting in more complete inventories; methodologies to gather data improve and the categorization of individual major emitters becomes better by getting more information on the individual emitters.

It is, however, key that the databases with the detailed information and calculation and the institutional knowledge are maintained and not lost in the time without inventory or reporting activities but that they are available for inventory update. This is a necessary part of QA. By this, the experience gained and the methodologies established are maintained, and an inventory update can build on this former knowledge and improve and refine the methodologies and the inventory. By this, the quality of inventories improves over time towards meeting more robust QA/QC criteria.

2.3.5 Time series

For inventory areas and sectors, time series can be useful to document trends and to spot outliers. Time trends are also needed for effectiveness evaluation (e.g., the reduction of unintentional POP release) and time series consistency.

The causes for outliers should be clarified in particular if calculation errors are the reason or if a specific cause can be found (e.g., a new facility with high emissions; regulatory change with particular restriction; e.g., in import or use). These specific causes should be explained. When methods or data have changed, check the consistency of time series inputs and calculations.

2.3.6 Material and substance flow analysis

Material flow analysis (MFA) systematically shows material flows through society in a comprehensive way (Brunner & Rechberger 2016). 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/substances starts at a source (e.g., production or import) and ends at a sink (e.g., export or landfill). Substance flow analysis (SFA) is a specific type of MFA used for tracing the flow of a selected chemical or group of substances (e.g., POPs or mercury) through a defined system (Brunner and Rechberger 2016). Therefore MFA/SFA can document the life cycle of materials containing POPs if appropriate inventory data are available.

For QA of MFA/SFA methods, the general MFA methodology, including stock and flow definitions and the use of explicit system definitions is needed (Brunner and Rechberger 2016). In addition, the "Guidelines for Data Modelling and Data Integration for Material Flow Analysis and Socio-Metabolic Research" (ISIE-SEM section board 2021) recommend the use of common classifications for materials, products and processes, e.g., the use of HS codes for commodities. Also, international classification and grouping of wastes should be considered like the United Nations University UNU-keys for WEEE (Balde *et al.* 2015). Conducting and presenting the results of inventories must be carefully designed to maximize the benefits of the results. This allows better external assessment and overall QA/QC.

Robust MFA/SFA methods can be used for QC of stocks and waste flows relevant for POP inventories such as EEE/WEEE or end-of-life vehicles: Based on data of imports (HS Codes or more specific import codes in certain countries or regions[5]) and production, dynamic MFA can, for example, model the amount of e-waste for different categories or the amount of end-of-life vehicles. The estimate from MFAs can be compared to the reported amount of treated WEEE and ELVs to calculate collection rates or illegal end-of-life practices (Islam and Huda 2019; Zimmermann *et al.* 2022).

2.3.7 Gaps in assessing major inventory areas and measures to address gaps

Some gaps/uncertainties may still exist at the end of the inventory including a lack of detailed information on certain activities and applications. An evaluation of the process, strategy used, and information collected can take place along with a decision on what further actions are needed to make the inventory more complete. The evaluation includes identification of the following (UNEP 2020):

[5] e.g., the MERCOSUR countries have more specific HS codes covering POPs.

- Gaps, uncertainties and limitations
- Need for validation of the information compiled in the inventory
- Actions needed to meet the requirements of the Stockholm Convention

Gap analyses conducted in the evaluation of an inventory could result in the need to contact some of these stakeholders again to get more information or identify other stakeholders to be contacted to help fill in the information and data gaps (see Box 3; GGKP 2024b). There are also other measures to address gaps and to improve or complete the inventory (Box 3).

In the evaluation step of the inventory, it needs to be decided which gaps could be addressed in the available time and which of the gaps will be addressed in the next round of inventory updates and therefore are included as a task in the action plan of the NIP.

Box 3: Approaches to fill gaps and improve the data quality

- Contact some of the stakeholders again to get more information or identify other stakeholders to be contacted to help fill the gaps (UNEP 2020).
- For inventory sectors with limited information, information campaigns and stakeholder meetings or workshops may be necessary.
- In some cases, government regulations may be required to ensure that stakeholders report their holdings, cooperate with the national authorities and engage in the national inventory. Drafting a regulation and making it come into force can result in data flow in advance of the regulatory act.
- Data gaps may (partly) be filled by estimations, interpolation, or extrapolation, which are valuable tools for providing data (proxy data); in particular, extrapolation of available statistical data might provide total quantities of a certain industrial POP in a country (UNEP 2020).
- If own country data are not available, then data from other countries with similar characteristics (e.g., region; industrial landscape; GDP/capita) are to be drawn.
- Monitoring and analysis of products, waste and recyclates can fill gaps (UNEP 2021b) (Tier III)
- For the long-term improvement of the data quality and storage it is recommended to develop a frame for compiling and storing data with main responsibility of the National Statistical Office and other governmental institutions and stakeholders where data are best compiled and stored in an appropriate database or other approaches (See GGKP 2024c).

The description of gaps, limitations and necessary actions to complete the inventory will also be valuable information for the NIP and action plan, especially for developing countries with a need for financial support for their inventory. It is important for developing countries to identify whether and what kind of technical and financial support will be necessary to address gaps and complete the inventory. Even if the inventory is very incomplete, the NIP is expected to provide information on gaps and the limitations of a country's resources and capabilities — information that is useful for identifying appropriate technical and financial needs.

2.3.8 Assessment and description of uncertainties and assumptions

In addition to gaps, inventories have certain uncertainties. Estimation, interpolation, or extrapolation provides the approximate data (proxy data) needed when resources are limited and capacity for measurements is limited or not available (Box 3). Information about assumptions and extrapolation and related uncertainties should be described in the inventory report and the NIP. Thus, the uncertainties in the inventories can be considered for project development and in the update of the inventory. Also, relevant uncertainties can be mentioned in the Article 15 reporting in the boxes for comments for individual inventories.

Applying MFA allows to some extent estimating unknown material flows if sufficient information about the process is available (e.g., amount of past imports, current stock and service life). Also, for MFA/SFA comprehensive data quality assessment and uncertainty characterization are important for profound uncertainty analyses, which lead to a better understanding of the reliability of MFA[6] results and of the need to improve underlying material flow data (Laner *et al.* 2016).

During the data processing, all the assumptions and conversion factors adopted should be noted/recorded and referenced (see also sections 2.3.1 and 2.3.2) when the results are described in the inventory report and the NIP. By the inclusion of this information, the developed time series can be better understood. When e.g., an outlier is assessed in a time series then the assumption and calculation of such an outlier can be retraced and possibly be corrected or an explanation can be given (see e.g., case study for POPs in the transport sector in Nigeria (Weber and Babayemi 2023).

2.4 Quality assurance and review

Quality assurance (QA) shows a planned and systematic pattern of all the activities necessary to provide adequate confidence that the inventory compilation will conform to established requirements (United Nations 2019). In general, a good practice for QA procedures includes reviews and audits to assess the quality of the inventory, to determine the conformity of the procedures taken and to identify areas where improvements could be made. QA procedures may be taken at different levels (internal/external), and they are used in addition to the general and substance-specific QC (IPPC 2006).

The objective of QA implementation is to involve reviewers who can conduct an unbiased review of the inventory and who may have a different technical perspective. It is important to use QA reviewers who have not been involved in preparing the inventory. Preferably these reviewers would be independent experts from other agencies, or national or international experts or groups not closely connected with the national inventory compilation, e.g., inventory experts of other countries. Where third-party reviewers who are independent of the inventory compiler are not available, persons who are at least not involved in the portion being reviewed can also perform QA (IPPC 2006).

It is good practice for inventory compilers to conduct a basic expert peer review of all categories before completing the inventory to identify potential problems and make corrections where possible. However, this will not always be practical due to timing and resource constraints. Inventory compilers may also choose to perform more extensive peer reviews or audits as QA procedures within the available resources (IPPC 2006).

2.5 Plausibility assessment

There are several practical and relatively simple plausibility techniques that do not require specialized calculation expertise or extended analyses. Most of these can be considered as method-based comparisons that consider the differences in national estimates based on using alternative estimation methodologies for the same inventory. These comparisons look for main

[6] The characterization and documentation of uncertainty in MFA has several advantages: (1) makes the definition of uncertainty transparent and enables reproducibility, (2) facilitates the creation of more reliable databases for MFA, (3) generates an understanding of the robustness of MFA results for decision support, and (4) allows for reconciling inconsistent data sets with the mass balance constraints of the model (Laner *et al.* 2015).

calculation errors. Method-based comparisons can be designed around the multi-tier level of methods outlined for each sector in the sector guidance, through comparisons to independent estimates developed by other institutions, and through cross-country comparisons with other inventories or measurements.

Plausibility checks can be extremely useful in confirming the reasonableness of national inventory estimates and may help identify calculation errors. Thus, plausibility checks should be considered as part of the continuous inventory assessment and development process. The results of these plausibility checks should be documented.

Since inventories are often calculated using national activity rates (amount of EEE, vehicles, AFFF firefighting foam, or metal production capacity) and POPs impact factors (PBDEs in polymers; PFOS content in AFFF; dioxin emission per tonne) both can have errors and need an individual check if data are considered not plausible.

2.5.1 POPs in current production and comparison with global production data

Currently only four POPs[7] or POPs groups are still produced, including DDT, decaBDE, PFOA and related compounds, and SCCPs (GGKP 2024b). Therefore, only these POPs are likely traded and imported as chemicals today. If POP inventories indicate that other POPs are imported as chemicals (e.g., indicated by non-specific HS codes), it is likely that other chemicals have been imported under this HS code and need further assessment.

If the import of currently produced POPs is recorded in the inventory, the amount can be compared with current or past production data and a plausibility check can be conducted if the recorded amount is reasonable (see Box 4).

Box 4: Example plausibility check of PFOS inventory results with global production data

> The use of HS codes for the assessment of PFOS imports into Turkey in 2014 where no PFOS-specific HS codes were available resulted in an overestimation of PFOS imports in the Tier II assessment phase with an upper estimate of 734 tonnes. In the evaluation phase of the inventories (Step 4), plausibility checks with the comparison with global PFOS production data (200 tonnes/year for 2014) revealed this overestimation, and therefore the HS code-based estimate was discarded (Korucu *et al.* 2015).
>
> The study also highlighted that non-specific HS codes cannot be used as a robust inventory base.
>
> Please note: PFOS and some related compounds received specific HS codes in 2017 and the last PFOS production stopped in 2021 (Chinese Ministry of Ecology and Environment 2022; GGKP 2024a).

2.5.2 POPs in products and comparison with total global production/use and service life

For most POPs, the global production and time of production are known, and information has been compiled (GGKP 2024b; Breivik *et al.* 2002; Paul *et al.* 2009; Abbasi *et al.* 2019; Chen *et al.* 2022; Li *et al.* 2023; Annex 1). For these POPs, the amount of inventoried POPs can be compared with former production data. This comparison of former total production and current inventory with consideration of per capita use indicates if the amount is reasonable or is likely

[7] A minor amount of PCN is produced, but only used as an intermediate for the production of polyfluorinated naphthalene (PFNs) in the same country and therefore PCNs are not traded.

an overestimation or underestimation (see country case studies in Boxes Box 4, Box 5 and Box 6).

Most industrial POPs were/are used as plastic additives (decaBDE tetraBDE/pentaBDE, hexaBDE/heptaBDE, HBCD, HBB, SCCPs) and PFOS/PFOA related substances are included in side-chain fluoropolymers (GGKP 2024a; OECD 2022). Also, the major production period and the stop of production are known for most POPs (GGKP 2024b; Li *et al.* 2022; Annex 1). Furthermore, for industrial POPs in products, their major use sectors with related service life are roughly known or can be developed (GGKP 2024a).[8] With this knowledge and country-specific data, material and substance flow analysis can be developed which documents the life cycle of the respective POP and their presence in use/stock and waste management (see case studies in Morf *et al.* 2007; Li *et al.* 2016; Liu *et al.* 2019; Weber and Babayemi 2023). This information can be used in dynamic MFA/SFA to assess if and to what extent these POPs are still in products and for how long they can be expected in use/stocks and waste management (Morf *et al.* 2007; Li *et al.* 2016; Liu *et al.* 2019, Weber and Babayemi 2023).

However, it needs to be stressed that most individual products are not labelled and only measurements can clarify if an individual product contains a POP.

Also, the outcome of the estimated POP amount in inventories of products of the major use sectors (e.g., EEE, transport, construction (GGKP 2024a)) can be compared to global production data for a plausibility assessment (e.g., per capita data).

Box 5: Example plausibility check of a SCCP/MCCP inventory and global production data

The amount of SCCPs and MCCPs imported to Nigeria for such major uses as PVC, rubber and PUR foam has been estimated and inventoried (Babayemi *et al.* 2022). The amount was estimated to be 73,000 tonnes for SCCPs and 149,000 tonnes for MCCPs and a ∑SCCP/MCCP of 222,000 tonnes for the period 1996 to 2019 (Babayemi *et al.* 2022). A comparison with global production (approx. 24 million tonnes of SCCP/MCCP between 1996 to 2020 (Chen *et al.* 2022)) and a per capita estimate (population of Nigeria of approx. 200,000 million; 2.5% of the world population) indicates that assuming an average distribution per capita would predict a total amount of approx. 600,000 tonnes for the sum of SCCP/MCCP importation/use in Nigeria. The inventoried amount is in the same order of magnitude and only a factor of 2 to 3 lower than the average use. The data are plausible considering an average lower resource use in Africa.

Box 6: Example plausibility check of the inventory of decaBDE in EEE/WEEE plastic and in vehicles in Nigeria and global decaBDE production data

The amount of decaBDE imported in EEE/WEEE to Nigeria for the period 1996 to 2021 is estimated in the PBDE inventory to 9,142 tonnes in cathode ray tube (CRT) housings of TVs and computers, 234 tonnes in LCD TV/monitors and 60 tonnes in other EEE, and therefore a total of 9,436 tonnes of decaBDE in EEE/WEEE (case study in Annex of GGKP 2024a). A comparison with global production of decaBDE (approx. 1,650,000 tonnes; see Annex 1; Li *et al.*. 2023) and a per capita estimate (population of Nigeria of approx. 200,000 million; 2.5% of the world population) indicates that assuming an average distribution per capita would predict a total amount of approx. 41,250 tonnes for decaBDE importation/use in Nigeria. Considering that approx. 30% of decaBDE was used in EEE (Abbasi *et al.* 2019), the amount for EEE/WEEE in Nigeria based on the per capita estimate would be expected

[8] The service life of products like cars or electronics can differ between countries with longer service life in developing countries.

to be 12,375 tonnes of decaBDE in EEE/WEEE plastics. This is in the same order of magnitude as the inventory of 9,436 tonnes decaBDE. While for a developing country, this close to average decaBDE use in EEE/WEEE seems high, an explanation is the high import of more than 10 million tonnes of CRTs largely as second-hand EEE and WEEE from 2000 to 2010. Therefore, the inventory was considered reasonable and plausible.

The amount of decaBDE in the 15,800,000 vehicles imported to Nigeria in the period 1980-2020 is estimated to be 1,484 tonnes (see case study in Annex of GGKP 2024a). Considering that 15% of the 1,650,000 tonnes of decaBDE was used in vehicles (Abbasi *et al.* 2019) an average per capita use for Nigeria would expect 6188 tonnes of decaBDE in the transport sector and therefore a factor of four more than the estimated 1,484 tonnes decaBDE. However, since in total only 61 vehicles are registered per 1000 people, this lower average amount was also considered plausible.

2.5.3 Comparison with POPs inventories in other countries

Hundreds of POPs inventories are documented in NIPs and inventory reports. Many research institutions have compiled and published POPs inventories in peer-reviewed scientific studies with or without material flow analysis and substance flow analysis (Morf *et al.* 2007; Sindiku *et al.* 2015; Li *et al.* 2016; Liu *et al.* 2019; Babayemi *et al.* 2022; Guida *et al.* 2022). Also, POPs inventory pilot case studies have been developed in the frame of UNEP/BRS Secretariat projects (GGKP 2024a; Guida and Weber 2019; Weber and Okonkwo 2019; Weber *et al.* 2021). Comparisons with other inventory data from countries in the region, or with similar economic development is a useful plausibility check. Also, methodologies and assumptions made in inventories, including descriptions of uncertainties, might give practical impulses for country inventories.

When conducting comparisons of POPs inventories, it is important to consider the following:

- Compare the system boundaries (sectors, inventory areas, country situation, etc.) if they fit the frame or aim of your inventory.
- Assess the data quality (e.g., QA/QC system or review), given uncertainties and assumptions and the plausibility of the assumptions and the data.

2.5.4 Comparison with international data sources

For certain inventory areas like EEE/WEEE or vehicles, data in developing countries might not be available or reliable. For some basic data in these POP use sectors, (GGKP 2024a) international institutions are compiling data, including country-specific data, which can be compared with data in the country as a plausibility check, or can be used if such information is not available in the country (IPCC 2019). Examples are the global compilation of EEE/WEEE data with country-specific information (Box 7) and the global compilation of vehicles in use for individual countries (Box 8). Also, the UN, the OECD and companies provide a wide range of statistical data that might be compared with national data.[9] Most of these international data sets already were subjected to QA/QC and an advantage is that they provide a good basis for comparison as they are consistent between countries.

[9] e.g. https://www.statista.com/; https://comtrade.un.org/; https://stats.oecd.org/; https://unstats.un.org.

Box 7: Comparison with international e-waste data of the Global E-waste Statistics Partnership[10]

National e-waste data can be compared with data from the Global E-waste Statistics Partnership compiled by the United Nations University (UNU) and the International Telecommunication Union (ITU) for individual countries. This partnership additionally publishes the amount of EEE new on the market for individual countries. These data can be compared with national statistics. If knowing or assuming an average lifespan of electronics of 10 to 15 years, these data can be used for interpolation and estimation of the total EEE in use in a country. Additionally, UNU with UNITAR publishes global and regional e-waste monitor reports which might be utilized for comparing national data.

Box 8: Comparison with global compilation of per capita possession of vehicles[11]

With appropriate references, a Wikipedia website[11] is compiling and updating the amount of vehicles per capita in the individual countries in the world. These data and also the references to the sources listed there can be compared with own generated data for plausibility check.

2.5.5 Comparison with measurements or monitoring

The impact factors or emission factors given in the Stockholm Convention inventory guidance documents, or the UNEP toolkit, are normally taken from peer-reviewed studies based on appropriate QA/QC. However, there might be regional differences in impact factors such as the major use of c-PentaBDE in North America (Abbasi *et al.* 2019) or the major production and use of SCCPs in China (Chen *et al.* 2021, 2022). While also this has been considered in inventory guidance documents with e.g., a particular impact factor for c-PentaBDE in vehicles (UNEP 2021c) the use of additional measurements can be useful and contribute to plausibility assessment and more robust inventory results (see e.g. Box 11). It needs to be stressed that a robust QA/QC procedure is needed for taking representative samples (Section 3.2; UNEP 2021a) and for the measurement (UNEP 2021b).

2.6 Documentation of how the inventory was calculated and proofs in inventory report

According to the general POPs inventory guidance (UNEP 2020) the final Step 5 is the documentation of the inventory report (Figure 1). This report includes results of inventories of all sectors investigated by the country compiled in a single document. It also includes information that documents the validity and transparency of data including information on QA/QC (Box 9).

Box 9: Recommended elements of an inventory report

- Objectives and scope.
- Responsibilities, institutional arrangements and procedures for the planning, preparation, and management of the inventory process.

[10] Global E-waste Statistics Partnership publish E-waste estimate data for each country for 2019. Additionally, they publish data on electrical and electronic equipment (EEE) new on the market https://globalewaste.org/country-sheets.
[11] https://en.wikipedia.org/wiki/List_of_countries_by_vehicles_per_capita

- Description of data methodologies used and how data were gathered, including all the assumptions and conversion and calculation factors adopted because of expert judgment.
- Changes in data inputs or methods from previous inventories (recalculations).
- Results of the inventory for each sector considered a priority for the country.
- Results of the gap analysis and limitations identified for completion of the inventory.
- Further actions (e.g., stakeholder involvement, data collection strategies) to be taken to complete the inventory and recommendations.
- Reference the source data and literature.
- QA/QC frame and procedure of the inventory.

Records of QA/QC procedures are important information to enable continuous improvement of inventory estimates. It is good practice for records of QA/QC activities to include the checks/audits/reviews that were performed, when they were performed, who performed them, and corrections and modifications to the inventory resulting from the QA/QC activity (IPCC 2006).

3 POPs Monitoring for Inventories/Implementation and Related QA/QC

3.1 Introduction

The POPs inventory guidance documents provide POP impact factors for certain products, such as for PBDEs, in relevant EEE categories or PBDEs in vehicles (UNEP 2021c). Almost all the inventories for polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF) are based on the emission factors compiled in the UNEP Toolkit[12] (UNEP 2013).

The UNEP toolkit encourages Parties to integrate their own measured emission data into the inventory (UNEP 2013). Similarly for new industrial POPs, their own impact factors for products and wastes can be generated by monitoring. Such a monitoring study was, for example, conducted in Nigeria for monitoring PBDEs and other BFRs in cathode-ray tube (CRT) casings within a capacity-building project (Sindiku *et al.* 2015; Box 11). Robust impact factors by monitoring POPs in products were also developed for PBDEs in EEE (Wäger *et al.* 2010; Hennebert and Filella 2018), SCCP/MCCP in products/materials (Chen *et al.* 2021; Box 13). However, when generating and using such data, it needs to be assured that measurements are representative and have adequate QA/QC.

3.2 Representativeness of samples and data

If own measured data are used, then it needs to be assured that the measurements are representative and accurate to ensure the necessary quality of the data. This is a particular challenge for industrial POPs in products and waste. For example, there are different WEEE categories with very different use amounts/frequency of POPs in the past. Therefore, different impact factors for different WEEE categories are given by the PBDE inventory guidance (UNEP 2021c). So national monitoring of POPs in WEEE would need to be developed for specific WEEE categories.

Since PBDEs might only be present in a few percent of equipment but then at high concentrations (up to 25%; Sindiku *et al.* 2015), a large number (several hundred to thousands) of shredded equipment is needed to get a representative sample. Therefore, for a representative sample, 3 to 7 tonnes of WEEE plastic per category need to be shredded with

[12] http://toolkit.pops.int

a sophisticated and standardized mixing of the shredded plastic to generate representative samples of some kg (Wäger *et al.* 2010; Hennebert and Beggio 2021). These samples need further milling in the laboratory to a small particle size (< 0.5 mm) to ensure that some grams of samples can be considered representative and can be extracted for chemical analysis. For more information, see the Stockholm Convention monitoring guidance on POPs in products and recycling (UNEP 2021b).

3.3 QA/QC of laboratory measurements

Measurements of POPs should be conducted according to international standard procedures. Measurements should be carried out in accredited laboratories where possible (e.g., according to ISO 17025), which are often not available in low- and middle-income countries. Other laboratories that have demonstrated their ability to produce reliable measurements, have appropriate QA/QC procedures in place and use international standard procedures could also produce reliable results and be used. International standards for the monitoring of POPs in products are compiled in the UNEP guidance for monitoring POPs in products and recycling (UNEP 2021b). Such international (ISO Standards) and regional/national standard procedures (e.g., CEN or EPA Standards) for the analysis of chemicals contain dedicated sections on QA/QC. However, often no ISO standard is available to measure POPs in products, waste and recycling (UNEP 2021b). Other measurement protocols sometimes do not contain a section on QA/QC. If no specific international or national standard procedures are available to be used by a laboratory, at least the following common procedures for the QA/QC of quantitative analysis of POPs should be considered (Box 10; UNEP 2021b).

Box 10: Common procedures for the QA/QC of quantitative analysis of POPs (UNEP 2021b)

- Clean laboratory equipment and chemicals to be used to avoid background contamination.
- Known and documented and repeated laboratory and field blank levels for the measured POPs.
- System ensuring that the effectiveness of the measurements and procedures are continuously supervised through the analysis of procedural blank samples.
- Regular injection of solvent blanks and standard solutions.
- Tests to be carried out to evaluate the accuracy of the method, e.g., the efficiency of the extraction methods, recovery of the analytes, stability, and loss of analytes in solution during storage, calibration using matrix-matched standards or standard addition and use of internal standards.
- Measurements of Certified Reference Materials (CRMs) if available.
- Tests to be carried out to evaluate the precision (repeatability and reproducibility), the limits of detection (LODs) and of quantification (LOQs), and the specificity of the whole method, from sampling to detection.
- Clearly defined criteria for identification and quantification need to be applied, and calibration curves need to be used.
- Storage of analyzed samples and data (including instrumental raw data) for a defined time.

3.4 Case studies for monitoring POPs in products in peer-reviewed studies

Due to the increased relevance of POPs in products like EEE/WEEE, the transport sector, building materials, carpets and textiles, a "Draft guidance on sampling, screening and analysis of persistent organic pollutants in products and recycling" was developed in the frame of the Stockholm Convention (UNEP 2021b). In this guidance, case studies from peer-reviewed studies are compiled in an Annex and can be assessed when, for example, developing a monitoring study of POPs in certain products in a country (UNEP 2021b). Three peer-reviewed case studies where selected plastic products were monitored for POPs are shortly described in Box 11, Box 12 and Box 13.

Box 11: Monitoring of PBDEs in e-waste plastic of Nigerian (Sindiku *et al.* 2015)

Due to the potential differences between the impact factors suggested in the *PBDE* Inventory Guidance (UNEP 2021a) and the Nigerian situation, a monitoring project to assess the PBDE content in plastic casings of TVs and computers in stocks in Nigeria has been conducted.

The following screening and analysis have been performed:

- Overall, 382 CRT monitors (224 PC CRTs and 158 TV CRTs; produced between 1980 to 2005 originating from Asia, Europe and North America; brands and models noted) have been screened with XRF for the bromine content (Sindiku *et al.* 2015).
- All 213 CRT polymer samples that were tested bromine positive (152 computer CRTs and 61 TVs) were analysed and quantified for PBDE and other BFRs.
- PBDE impact factors for computers and TV casings were developed and were somewhat higher for TVs compared to the impact factor suggested by the inventory guidance.

The study was conducted in cooperation with an experienced research institution analyzing additives in plastic and conducting research on recycling WEEE plastic for twenty years (Fraunhofer Institute Freising, Germany) The study included the capacity building of a Nigerian researcher. The monitoring project was supported by the BRS Secretariat and funded by the Norwegian government as a "small grants project".

Box 12: Monitoring of PBDEs and HBCD in cars in Japan (Liu *et al.* 2019)

The inventory of PBDEs and HBCD in cars in Japan was based on monitoring of PBDEs and HBCD in more than 500 plastic parts of more than 60 cars by the National Laboratory of Environmental Studies, Japan. A basis on the monitoring impact factors of average PBDE and HBCD content in cars was developed and used for a national PBDE/HBCD assessment and inventory for cars combined with an MFA/SFA (Liu *et al.* 2019).

Box 13: Monitoring of SCCPs and MCCPs in major use area in China (Chen *et al.* 2021)

A research group in China monitored SCCPs and MCCPs in major polymer products (PVC, rubber, PUR foam) to establish a country inventory (Chen *et al.* 2021). More than 120 samples were analysed by a commercial laboratory having ISO accreditation. The results were used to develop the first impact factors for SCCP/MCCPs for major plasticized PVC, rubber and PUR categories (Chen *et al.* 2021).

The three case studies also show that impact factors for inventory development can be based on their own measured data to complement or substitute impact factors suggested by inventory guidance documents for establishing national POPs inventories.

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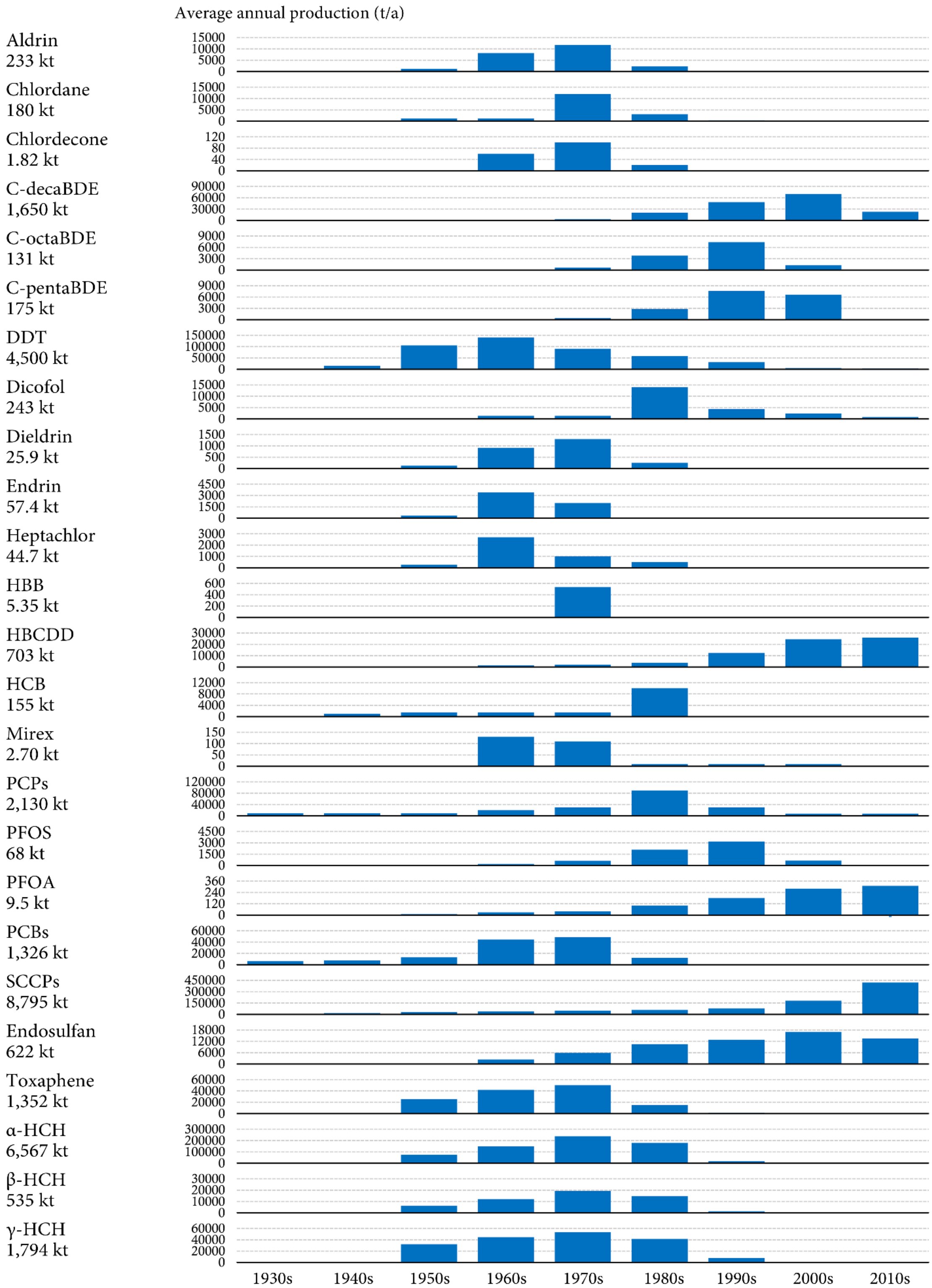
Annex 1: Global Production Data and Time of Production of Intentionally Produced POPs

Figure 3: Average annual global productions* of the 25 intentionally produced POPs from the 1930s to the 2010s. (Li *et al.* 2023).



*Numbers under the chemical names on the left indicate the central tendency estimate of the global cumulative production in kilotonnes (kt)