2nd Phase of Extended PCB Inventory in Indonesia under The Project "Introduction of an Environmentally – Sound Management and Disposal System for PCB Wastes and PCB – Contaminated Equipment

Statistics Report

2021

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1 Introduction

1.1 Background

The Stockholm Convention on Persistent Organic Pollutants is an international environmental treaty that aims to eliminate or restrict the production and use of persistent organic pollutants (POPs), as these substances can inflict harmful impacts on human health and on the environment. Polychlorinated Biphenyls (PCBs) that contaminates transformer oil is one of the substances that can be categorized as POPs. For Indonesia, the ratification of Stockholm Convention On Persistent Organic Pollutants was established through the issuance of Law No. 19 of 2009.

As stated in the 2008 National Implementation Plan (NIP), which was reviewed and updated in 2014, PCBs removal and disposal are among Indonesia's national priorities in implementing the Stockholm Convention on Persistent Organic Pollutants (POPs). In regards to the NIP, The Ministry of Environment and Forestry (MoEF) and UNIDO conducted the 2nd Phase of Extended PCBs Inventory in Indonesia under the Project "Introduction of an Environmentally – Sound Management and Disposal System for PCBs Wastes and PCBs – Contaminated Equipment". PT. Petrolab Services (Petrolab) has been awarded as contractor to assist MoEF and UNIDO in the project.

The project was a continuation of the 1st Phase of Extended PCBs Inventory project in 2015-2016, which collected 3,015 samples from Java Island. For this 2nd phase, the sampling involved 62 private companies located in 12 provinces in Java and Sumatra, and PT. Perusahaan Listrik Negara (PT. PLN—Indonesia Electrical Company) equipment all over Indonesia. The project focuses on nine (9) energy-intensive industrial sectors, which are: 1) pulp and paper; 2) oil refinery, 3) smelter/metallurgy; 4) iron and steel; 5) power plant; 6) mining; 7) oleochemical; 8) oil & gas; and 9) petrochemical/fertilizer. It is to be noted that the transformers that were sampled during the 1st phase inventory are not taken as samples again for the 2nd phase inventory. Hence, this project avoided double-sampling of transformers.

In its implementation, the project outputs included a statistics report of the updated PCBs inventory database and a PCBs Management Plan with action plan towards PCBs phasing out in 2028. This Statistics Report provided statistical analysis results of PCBs inventory data from the 1st phase (2015-2016) and the 2nd phase (2019-2020) of sampling.

1.2 Objectives and Research Questions

The purpose of the 2nd PCBs extended inventory project in general was derived from one of the priorities and key objectives stated in the National Implementation Plan (NIP), which was to "measure PCBs contamination, especially in mining activities, industrial zones and power plant, ships and vessels". More specifically, the objective of the project was to establish at least 1500 samples inventory and to update the PCBs Management Plan.

As part of the reports of the 2nd PCBs extended inventory project, the objective of this Statistics Report in particular is to provide statistical analysis of the updated PCBs inventory database and to generate insights resulted from those analysis, as an input for the arrangement of PCBs Management Plan. The research questions used in conducting the analysis were:

1. Considering the lack of transformers database in Indonesia, can we estimate the total population of transformers in Indonesia and its general characteristics of PCBs contamination?
2. What are the technical factors that correlate with transformers' PCBs contamination?
3. How reliable is Dexsil analyzer with Askarel-A conversion approach for screen-testing PCBs contamination? Does it produce similar results with GC-ECD instrument with IEC-61619 method?

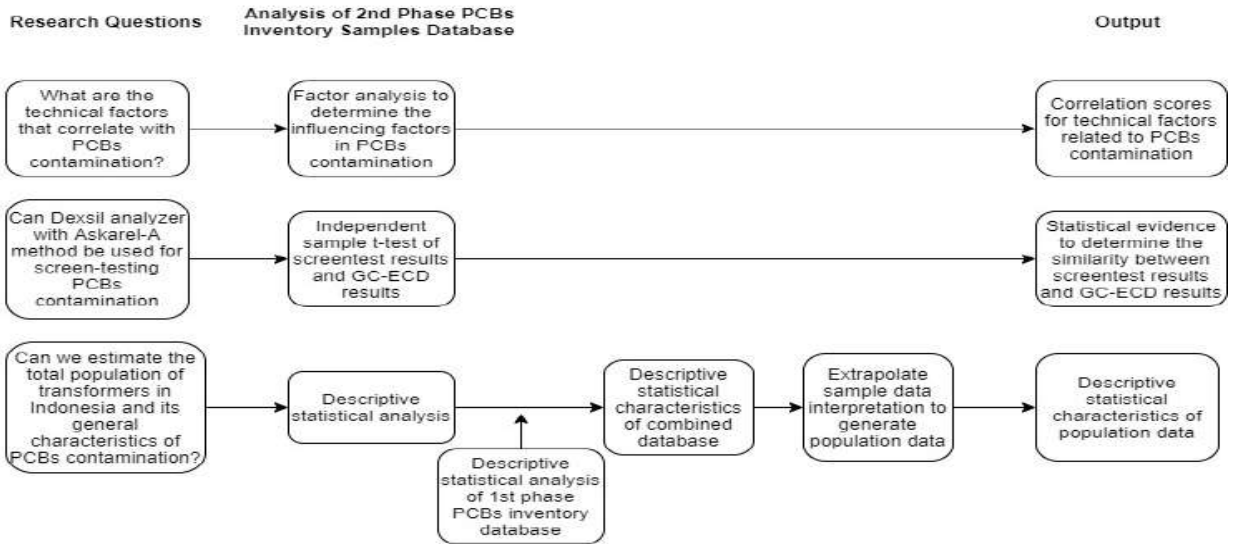
1.3 Statistical Analysis for PCBs Inventory Database

The main content in this report was split into 2 (two) main chapters as follow:

1. Chapter 2: Data Interpretation
   This report elaborates more on descriptive statistical analysis of both 1st phase and 2nd phase PCBs inventory database, determine the most influential factors of PCBs contamination, and provides early comparison analysis between Dexsil screentest and GC-ECD IEC-61619 test.
2. Chapter 3: Extrapolation to Estimate Population Data
   This analysis used Indonesia's Economic Census 2016 (EC-2016) as basis to estimate the population data, combined with the existing database of industries. The results of sample data interpretation were then extrapolated to estimate population data (national-scale).

The workflow for the whole statistical analysis was as follow:

Figure 1-1 Statistical Analysis Workflow



2 Data Interpretation

2.1 Data Interpretation for PCBs Inventory Database

Data interpretation for PCBs Inventory Database was conducted firstly by applying descriptive statistical analysis and categorization for data gathered from the 1st phase (2015-2016) and 2nd phase (2019-2020) inventory. The analysis was then applied to the combined data from the 1st and 2nd phase inventory. The main function of this analysis was to provide categorisation of PCBs contamination status based on several main variables.

The next analysis in data interpretation was to determine the most influential factors of PCBs contamination. The expected output of this analysis was to identify the variable(s) that can be used for quick assessments or initial indicators of PCBs contamination in a transformer.

The last analysis in data interpretation was comparison between screentest results and GC-ECD IEC-61619 results. From the inventory data, GC-ECD IEC-61619 tests showed different results compared to the screentest using Dexsil. The analysis was expected to identify the deviation of results from these two instruments, and provided insights on the reliability of the screentest results.

2.2 Approach and Methods Used

The approach and methods used for data interpretation were as follow:

1. To identify the technical variables that are most correlated with PCBs contamination, the one-way ANOVA method was used.
   One-way ANOVA described the variability and correlation between an observed variable with PCBs contamination test results. This is to identify which factors correlate with PCBs contamination.

2. To compare the results of sample test using Dexsil and GC-ECD IEC-61619, the independent samples t-test was used. In this project, Dexsil instrument was utilised as a screentest or rapid-test for all the samples due to it is more economical and is faster in providing results. A small part of the sample was then randomly selected for GC-ECD IEC-61619 test. The independent samples t-test method compares the means of two independent groups (in this case the Dexsil results and the GC-ECD IEC-61619 results) in order to determine whether there is statistical evidence that the associated population means are significantly different. The Dexsil test method used in the PCBs inventory is the askarel-A conversion approach.

3. Descriptive analysis was done by:
   a. Sampling distribution and PCBs contamination statistics related to the following variables:
      - Region/province

- industry type
- types of equipment
- manufacture year

b. The range of transformer manufacture year is as follows:
   - pre-1982
   - 1983 – 1992
   - 1993 – 2002
   - 2002 – 2012

c. The degree of PCBs contamination uses the following range:
   - PCBs < 50 ppm (considered as not contaminated)
   - 50 ppm ≤ PCBs < 10,000 ppm (considered as contaminated)
   - PCBs ≥ 10,000 ppm (considered as contaminated/pure PCBs)

2.3 Assumptions Used and Limitations of Analysis

The analysis on Data Interpretation was done under the following assumptions and limitations:

- The sampling method and structure for the 1st phase PCBs inventory and the 2nd phase PCBs inventory were different. Therefore, the sample database may not fully ideal for the analysis. However, in terms of sample quantity, the number of samples was adequate to produce a reliable/valid result.
- No samples from the 1st phase PCBs inventory were re-sampled on the 2nd phase PCBs inventory.
- The 2020 sampling data was more purposive and focused on particular sectors/types of industry. This was different with 2016 sampling data which covered a broader range of economic sectors. The analysis re-categorized both datasets using the economic sectors division in Indonesia's Economic Census (*Sensus Ekonomi*) 2016 as reference.
- Some inaccuracies may occur during the recategorization process, and some company data may be neglected due to double inputs of industry types and location. For example, there were some companies which were categorized in 2 or more industry types and located in 2 or more provinces. Some of these companies were not used in the analysis to avoid confusions.

2.4 Factor Analysis

Factor analysis was used to identify the technical variables that were most correlated with PCBs contamination. In this project, the factor analysis used one-way ANOVA method. One-way ANOVA was used to describe variability and correlation between an observed variable with PCBs contamination test results.

There were four 4 technical variables tested in this analysis, which were chosen by considering the completeness of data. The variables were as follow:

1. Manufacture year
2. Power rating
3. Voltage

4. Type of equipment

These variables were analysed against the PCBs contamination value resulted from testing of samples using Dexsil L2000DX. The PCBs contamination value resulted from testing using Gas Chromatography (GC-ECD IEC-61619) was not used in factor analysis because only 15.8% of the samples were tested using this instrument, thus would significantly reduce the number of samples for the analysis.

The factor analysis was conducted during the 2nd quarter of the project. In this quarter, the number of samples from the 2nd phase PCBs inventory were still 1,254 (another sampling activity was then conducted in the 3rd quarter of the project and gathered 255 samples, making the total number of samples for the 2nd PCBs inventory to become 1,509 samples). Hence, the total number of samples used in factor analysis were 4,267 (comprised of 3,013 samples from the 1st phase PCBs inventory and 1,254 samples from the 2nd phase PCBs inventory). Nevertheless, this total number of samples was adequate to perform the analysis.

2.4.1 Manufacture year

There were 4,232 samples used in analysing the correlation between manufacture year and PCBs contamination number. From the available 42,67 samples when the analysis was conducted, the manufacture year data was not available in 27 samples, and needed reconfirmation in another 8 samples. In consistency with the descriptive analysis, manufacture year were classified into four categories. The categories and the number of samples from each category used in the analysis were as follow:

1) 602 samples from the category of transformers manufactured before 1983;
2) 1,089 samples from the category of transformers manufactured 1983-1992;
3) 1,417 samples from the category of transformers manufactured 1993-2002; and
4) 1,124 samples from the category of transformers manufactured 2002-2012.

The analysis result was as follow:

```
. oneway dexsilpcb yearcategory, tabulate

yearcategor |      Summary of dexsilpcb
          y |       Mean   Std. Dev.       Freq.
------------+------------------------------------
1983 - 1992 |  24.062902   125.72575        1089
1993 - 2002 |  30.226373   139.74823        1417
     < 1983 |  148.16912   549.78178         602
     > 2002 |  15.856993   134.83873        1124
------------+------------------------------------
      Total |  41.601215   245.51179        4232

                    Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      8100001.83      3   2700000.61     46.23     0.0000
 Within groups       246927914   4228    58403.007
------------------------------------------------------------------------
    Total            255027916   4231   60276.0377

Bartlett's test for equal variances:  chi2(3) =  3.3e+03  Prob>chi2 = 0.000
```

From the analysis, the summary mean of each category showed significant difference, particularly for the transformers manufactured before 1983. This meant that there was a statistically significant difference between each category in relation to the PCBs contamination value (Dexsil testing results), as determined by the test result ***p* = 0.000** (test result value $p < 0.05$ was the parameter defined as statistically significant difference). Therefore, it can be concluded that 'Manufacture Year' was a significant variable that influenced (or became a factor of) PCBs contamination value.

2.4.2 Power Rating

According to size and power rating, transformers were classified into three (3) categories:

1. Large Power Transformers (LPT): This group covers transformers with power rating normally above 200 MVA (limits used range between 100 and 250 MVA) and High Voltage (HV) of usually at least 220 kV.
2. Medium Power Transformers (MPT): This group includes transformers with power rating range from 60 to 200 MVA and high voltage up to around 275 kV.
3. Small Power Transformers (SPT): This group includes transformers from roughly 10 to 60 MVA and a maximum service voltage of 170kV.

There were 4,143 samples used in analysing the correlation between power rating and PCBs contamination number. The categories and the number of samples from each category used in the analysis were as follow:

1. 6 samples from the category of Large Power Transformers (LPT);
2. 52 samples from the category of Medium Power Transformers (MPT); and
3. 4,085 samples from the category of Small Power Transformers (SPT).

The analysis result was as follow:

```
. oneway dexsilpcb powerratingkva, tabulate

      Power
     rating |      Summary of Dexsil (PCB)
      (KVA) |       Mean   Std. Dev.       Freq.
------------+------------------------------------
        LPT |  19.346666   34.032492           6
        MPT |  8.7259617   13.772588          52
        SPT |  42.411447   248.65045        4085
------------+------------------------------------
      Total |  41.955247   246.94095        4143

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      61334.6915      2   30667.3458      0.50    0.6049
 Within groups       252517131   4140   60994.4762
------------------------------------------------------------------------
    Total            252578466   4142   60979.8325

Bartlett's test for equal variances:  chi2(2) = 249.7412  Prob>chi2 = 0.000
```

From the analysis, the summary mean of each category showed significant difference. However, there was no statistically significant difference between each category in relation to the PCBs contamination value (Dexsil testing results), as determined by the test result ***p* = 0.6049** (test result value $p < 0.05$ was the parameter defined as statistically significant difference). Therefore, it can be concluded that 'Power Rating' was not a significant variable that influenced (or became a factor of) PCBs contamination value.

2.4.3 Voltage

Based on nominal system voltage, power transformers are categorised as follow:

1. Category O: power transformers with nominal system voltage 400kV and above
2. Category A: power transformers with nominal system voltage above 170kV and below 400kV
3. Category B: power transformers with nominal system voltage above 72.5kV and up to and including 170kV (other than those in category A)
4. Category C: power transformers for MV/LV application, e.g. nominal system voltages up to and including 72.5kV and traction transformers (other than those in category A)

There were 4,153 samples used in analysing the correlation between voltage and PCBs contamination number. The categories and the number of samples from each category used in the analysis were as follow:

1. 11 samples from category A
2. 75 samples from category B
3. 4,064 samples from category C
4. 3 samples from category O

The analysis result was as follow:

```
. oneway dexsilpcb voltage , tabulate

                Summary of dexsilpcb
    voltage |      Mean   Std. Dev.       Freq.
------------+------------------------------------
 Category A |   6.8836363   4.3315546          11
 Category B |   34.666933   186.57983          75
 Category C |    42.59233   249.28856        4064
 Category O |   5.8900001    2.915013           3
------------+------------------------------------
      Total |    42.32811    247.8681        4153

                           Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      22488.3647        3   7496.12156       0.12   0.9472
 Within groups       255070554     4149   61477.5979
------------------------------------------------------------------------
    Total            255093042     4152   61438.5939

Bartlett's test for equal variances:  chi2(3) =  90.7604  Prob>chi2 = 0.000
```

From the analysis, the summary Mean of each category showed significant difference. However, there was no statistically significant difference between each category in relation to the PCBs contamination value (Dexsil testing results), as determined by the test result ***p* = 0.9472** (test result value $p < 0.05$ was the parameter defined as statistically significant difference). Therefore, it can be concluded that 'voltage' was not a significant variable that influenced (or became a factor of) PCBs contamination value.

2.4.4 Type of Equipment

There were 4,239 samples used in analysing the correlation between type of equipment and PCBs contamination number. The categories and the number of samples from each category used in the analysis were as follow:

1) 189 samples of Power Transformers
2) 4,040 samples of Distribution Transformers
3) 10 samples of others

The analysis result was as follow:

```
. oneway dexsilpcb typeofequipment , tabulate

                    Summary of Dexsil (PCB)
Type of Equipment        Mean   Std. Dev.       Freq.
------------------------------------------------------
           Others      11.311   12.968327          10
Trafo Distribut..   41.891092   247.62781        4040
      Trafo Power   8.6259789   19.509154         189
------------------------------------------------------
            Total   40.335794   241.88134        4239

                          Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      208238.786        2   104119.393       1.78     0.1687
 Within groups      247742655     4236   58485.0461
------------------------------------------------------------------------
    Total           247950894     4238   58506.5819

Bartlett's test for equal variances:  chi2(2) = 792.6601  Prob>chi2 = 0.000
```

From the analysis, the summary mean of each category showed significant difference. However, there was no statistically significant difference between each category in relation to the PCBs contamination value (Dexsil testing results), as determined by the test result p = 0.1687 (test result value p < 0.05 was the parameter defined as statistically significant difference). Therefore, it can be concluded that 'type of equipment' was not a significant variable that influenced (or became a factor of) PCBs contamination value.

2.5 Independent Sample t-test

The PCBs inventory testing activities for this project used the Dexsil L2000DX portable analyzers, which was considered appropriate to test large sets of samples, as it shows results more rapidly and is more economical. In using the Dexsil analyzers, this project used Askarel A conversion approach in consistency with the method used in the previous 1st phase of PCB inventory and considering the origin of PCBs in transformer oil.

A small part of the sample was then randomly selected for GC-ECD IEC-61619 test. The GC-ECD IEC-61619 method took longer time to produce results and was more expensive, but was considered more accurate. The method for Gas Chromatography analysis used the European standard IEC 61619.

The independent sample t-test was used to compare results of sample testing using Dexsil (askarel A) and GC-ECD (IEC 61619). The independent samples t-test method compares the results of both tests in order to determine whether there is statistical evidence that the associated population means are significantly different.

2.5.1 Dexsil (Askarel-A) and GC-ECD IEC-61619 Test Results Comparison for the 2st Phase PCBs Inventory

The independent sample t-test for the 2nd phase PCBs inventory compared the result values of PCBs testing using Dexsil (askarel A) and GC-ECD IEC-61619 for 236 samples observation. The analysis result was as follow:

Two-sample t test with equal variances

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
PCBTes~d	236	47.00665	9.485112	145.7131	28.31994	65.69337
GCEDC_~t	236	59.25017	10.35042	159.0062	38.8587	79.64164
combined	472	53.12841	7.017805	152.4657	39.33833	66.91849
diff		-12.24352	14.03918		-39.83084	15.34381

diff = mean(PCBTest_Askare~d) - mean(GCEDC_Test) t = -0.8721
Ho: diff = 0 degrees of freedom = 470

Ha: diff < 0 | Ha: diff != 0 | Ha: diff > 0
Pr(T < t) = 0.1918 | Pr(|T| > |t|) = 0.3836 | Pr(T > t) = 0.8082

From the analysis, the group Means did not show significant difference, as the summary Mean of each category showed significant difference the *p*-value in the **Pr(|T| > |t|)** row (under **Ha: diff != 0**) was 0.3836. This *p*-value (which is more than 0.05) showed that statistically the Mean of PCBs testing results using Dexsil Askarel A (47.01) and the Mean of PCBs testing results using GC- ECD (59.25) were not significantly different. Therefore, it can be concluded that the two testing methods used to test the 2nd phase PCBs inventory samples produced similar results.

2.5.2 Dexsil (Askarel-A) and GC-ECD IEC-61619 Test Results Comparison for the 1st Phase and 2st Phase PCBs Inventory (Combined)

The independent sample t-test for the whole PCBs inventory database (1st phase and 2nd phase PCBs inventory samples combined) compared the result values of PCBs testing using Dexsil (askarel A) and GC-ECD IEC-61619 for 397 samples observation. The analysis result was as follow:

```
. ttest PCBTest_AskarelMethod == GCEDC_Test, unpaired

Two-sample t test with equal variances

Variable     |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
-------------+--------------------------------------------------------------------
PCBTes~d     |     397    147.6727     20.1224     400.936    108.1126    187.2328
GCEDC_~t     |     397    124.9085     16.65189    331.7866   92.17135    157.6457
-------------+--------------------------------------------------------------------
combined     |     794    136.2906     13.05747    367.9334   110.6593    161.9219
-------------+--------------------------------------------------------------------
    diff     |            22.76421     26.11889               -28.50623   74.03465
------------------------------------------------------------------------------
    diff = mean(PCBTest_Askare~d) - mean(GCEDC_Test)              t =   0.8716
Ho: diff = 0                                     degrees of freedom =      792

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.8081         Pr(|T| > |t|) = 0.3837          Pr(T > t) = 0.1919
```

From the analysis, the group Means did not show significant difference, as the summary Mean of each category showed significant difference the p-value in the **Pr(|T| > |t|)** row (under **Ha: diff != 0**) was 0.3837. This p-value (which is more than 0.05) showed that statistically the Mean of PCBs testing results using Dexsil Askarel A (147.67) and the Mean of PCBs testing results using GC-ECD IEC-61619 (124.91) were not significantly different. Therefore, it can be concluded that the two testing methods used to test the combined 1st phase and 2nd phase PCBs inventory samples produced similar results.

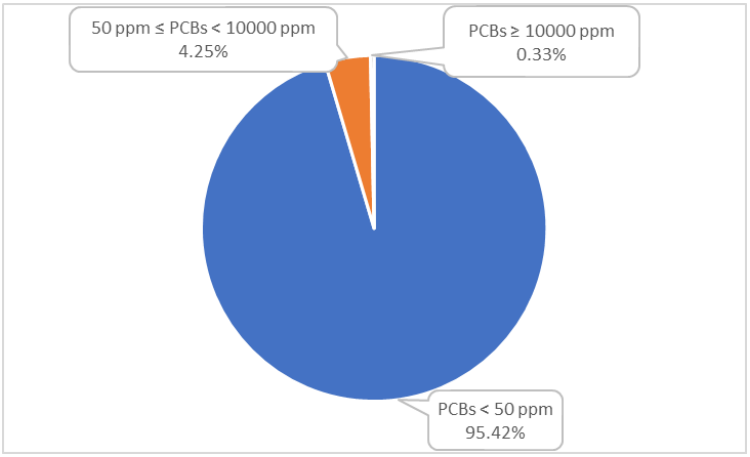
2.6 Descriptive Analysis Results for 1st Phase of PCBs Inventory

The 1st phase of PCBs Inventory project was done in all provinces in Java Island for eight (8) months from October 2015 to May 2016. A total of 3,015 transformers were sampled and tested from more than 1,000 voluntarily participating companies. The testing result showed that there were 128 or 4.25% samples contaminated by PCBs with contamination ≥50ppm but less than 10,000ppm, and 10 or 0.33% samples contaminated by PCBs ≥ 10,000ppm.

Table 2-1 PCBs Contamination Status of 1st Phase PCBs Inventory Samples

PCB Status	Num of sample (trafo)	Percentage (%)
PCBs < 50 ppm	2,877	95.42%
50 ppm ≤ PCBs < 10,000 ppm	128	4.25%
PCBs ≥ 10,000 ppm	10	033%
Total	*3,015*	*100.00%*

Figure 2-1 PCBs Contamination Status Proportion, 1st Phase PCBs Inventory



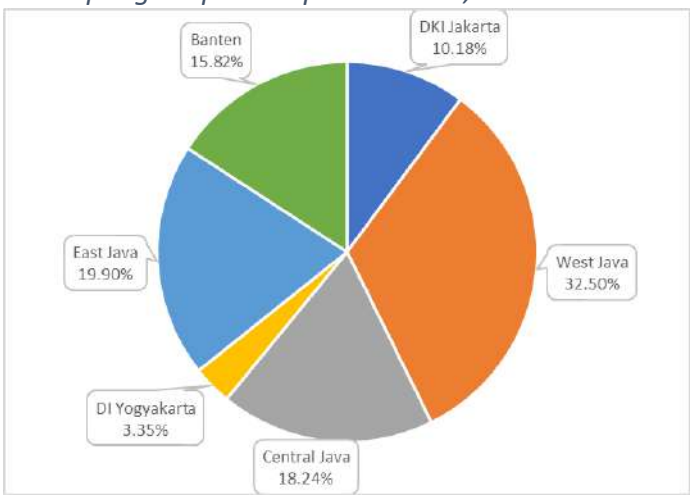
2.6.1 PCBs Contamination Status per Province

The data collected from the 1st phase of PCBs Inventory were 3,015 transformers in total from six (6) provinces in Java Island. In terms of sampling proportion, the highest number of samples were taken from West Java Province with 980 samples (32.5%). East Java and Central Java were the 2nd and 3rd province with the highest number of samples with 600 (19.9%) and 550 (18.24%) samples, respectively.

Table 2-2 Sampling Proportion per Province, 1st Phase PCBs Inventory

Province	Number of Samples (trafo)	Percentage (%)
DKI Jakarta	307	10.18%
West Java	980	32.50%
Central Java	550	18.24%
DI Yogyakarta	101	3.35%
East Java	600	19.90%
Banten	477	15.82%
Total	**3,015**	**100.00%**

Figure 2-2 Sampling Proportion per Province, 1st Phase PCBs Inventory



In terms of PCBs contamination status, DKI Jakarta was the province with the highest proportion of PCBs contaminated samples (50 ppm ≤ PCBs < 10,000 ppm) with 7.49%. East Java and West Java province followed behind with 6.33% and 4.90% respectively. There were 4 provinces that have samples contaminated with PCBs more than 10,000ppm, with West Java being the province with the highest number of proportions in this category (0.61%). None of the samples from DI Yogyakarta was contaminated with PCBs. More detail breakdown can be found in the following tables.

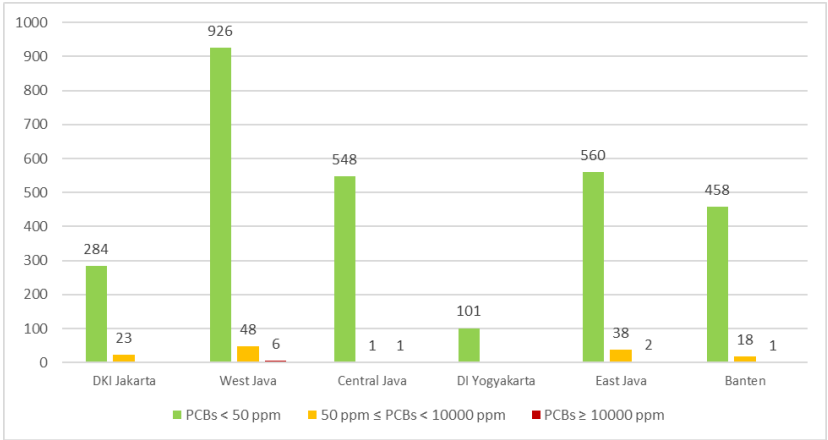
Table 2-3 PCBs Contamination Status per Province, 1st Phase PCBs Inventory

Province	PCBs Contamination Status			
	Number of Samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
DKI Jakarta	284	23	0	307
West Java	926	48	6	980
Central Java	548	1	1	550
DI Yogyakarta	101	0	0	101
East Java	560	38	2	600
Banten	458	18	1	477
TOTAL	*2,877*	*128*	*10*	*3,015*

Table 2-4 PCBs Contamination Status Percentage per Province, 1st Phase PCBs Inventory

Province	PCBs Contamination Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
DKI Jakarta	92.51%	7.49%	0.00%	100.00%
West Java	94.49%	4.90%	0.61%	100.00%
Central Java	99.64%	0.18%	0.18%	100.00%
DI Yogyakarta	100.00%	0.00%	0.00%	100.00%
East Java	93.33%	6.33%	0.33%	100.00%
Banten	96.02%	3.77%	0.21%	100.00%
TOTAL	*95.42%*	*4.25%*	*0.33%*	*100.00%*

Figure 2-3 PCBs Contamination Status per Province, 1st Phase PCBs Inventory



2.6.2 PCBs Contamination per Type of Industry

In the 1st phase of PCBs Inventory project, there were no particular types of industry as focus for sampling. Hence, there was a wide variety of industry sectors in the sample database, and there was no particular reference for classification. Therefore, this analysis needed to use a new reference to classify the types of industry in the sample data. After some discussion with UNIDO and MoEF, the project agreed to use Indonesia's Economic Census 2016 (IEC 2016) document as reference.

In the IEC 2016 document, there were thirteen (13) sectors/types of industry in Indonesia. After a thorough examination, the 1st phase PCBs inventory sample data was then reclassified based on the 13 industry sectors/types of IEC 2016. As a result, there were five (5) main sectors of industry that were considered appropriate to accommodate the sample data, which were as follow:

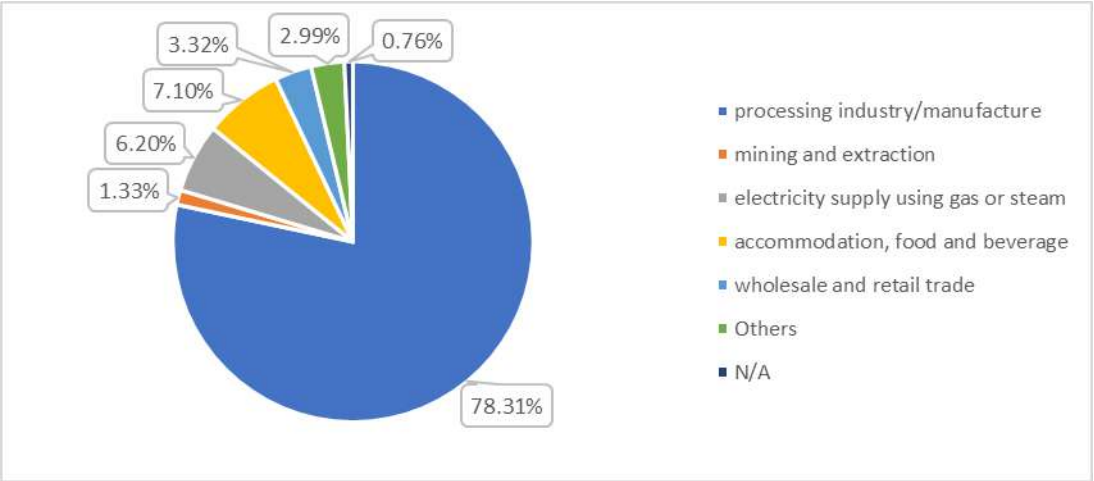
1. Processing industry/manufacture *(Industri pengolahan*) with 2,361 samples
2. Mining and extraction (*Pertambangan dan penggalian*) with 40 samples
3. Electricity supply using gas or steam (*Pengadaan listrik gas/uap air panas*) with 187 samples
4. Accommodation, food and beverage (*Penyediaan akomodasi dan makan minum*) with 214 samples
5. Wholesale and retail trade (*Perdagangan besar dan eceran*) samples with 100 samples

Outside these five main types of industry, there were 90 samples with a large variety of industry types. Therefore, all of those 90 samples were then classified as Other Industries (*Industri lainnya*). There were also 23 samples with no data regarding their types of industry. The proportion of sample data per type of industry can be found in the following table.

Table 2-5 Sampling Proportion per Type of Industry, 1st Phase PCBs Inventory

Industry type	Number of Samples (trafo)	Percentage (%)
processing industry/manufacture	2,361	78.31%
mining and extraction	40	1.33%
electricity supply using gas or steam	187	6.20%
accommodation, food and beverage	214	7.10%
wholesale and retail trade	100	3.32%
Others	90	2.99%
N/A	23	0.76%
TOTAL	*3,015*	*100.00%*

Figure 2-4 Sampling Proportion per Type of Industry, 1st Phase PCBs Inventory



In terms of PCBs contamination status (50 ppm ≤ PCBs < 10,000 ppm), the *penyediaan akomodasi dan makan minum* (accommodation, food and beverage) industry was the industry sector with the highest proportion of PCBs contaminated samples with 5.61%. The *industri lainnya* (other industries) followed closely with 5.56% samples contaminated by PCBs. The sectors *pertambangan dan penggalian* (mining and extraction) and *industri pengolahan* (processing industry) were the next sectors with most samples contaminated by PCBs, with 5% and 4.24%, respectively. There were 10 samples (0.42%) contaminated by PCBs with concentration more than 10,000 ppm in *industry pengolahan.* More detail breakdown can be found in the following tables.

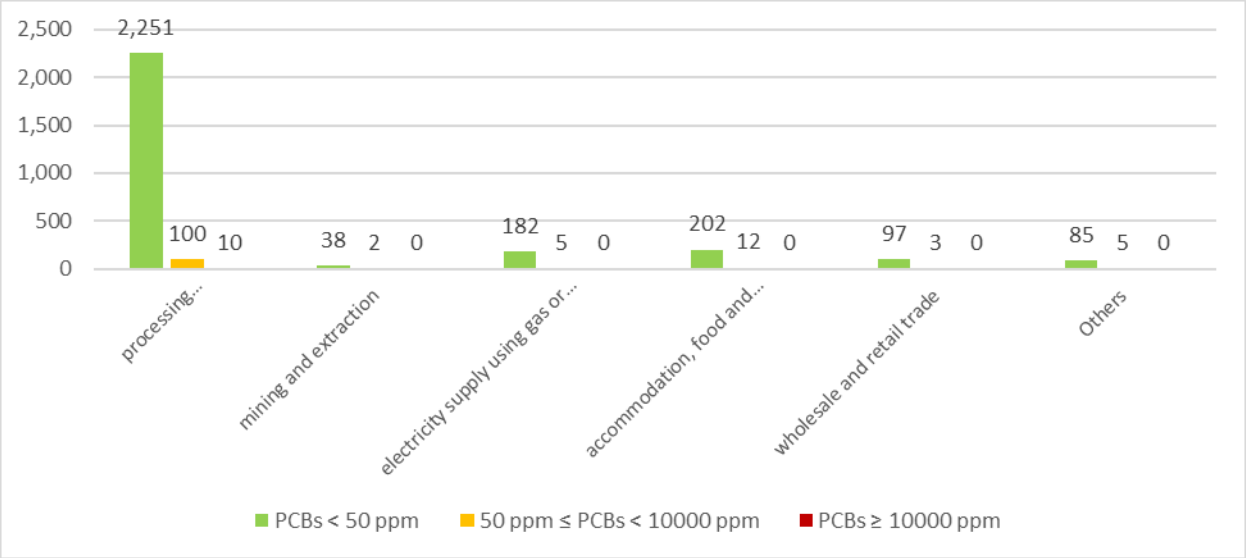
Table 2-6 PCBs Contamination Status per Type of Industry, 1st Phase PCBs Inventory

Industry Type	Status			
	Number of Sample (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
processing industry/manufacture	2,251	100	10	2,361
mining and extraction	38	2	0	40
electricity supply using gas or steam	182	5	0	187
accommodation, food and beverage	202	12	0	214
wholesale and retail trade	97	3	0	100
Others	85	5	0	90
N/A	22	1	0	23
TOTAL	*2,877*	*128*	*10*	*3,015*

Table 2-7 PCBs Contamination Status Proportion per Type of Industry, 1st Phase PCBs Inventory

Industry Type	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
processing industry/manufacture	95.34%	4.24%	0.42%	100.00%
mining and extraction	95.00%	5.00%	0.00%	100.00%
electricity supply using gas or steam	97.33%	2.67%	0.00%	100.00%
accommodation, food and beverage	94.39%	5.61%	0.00%	100.00%
wholesale and retail trade	97.00%	3.00%	0.00%	100.00%
Others	94.44%	5.56%	0.00%	100.00%
N/A	95.65%	4.35%	0.00%	100.00%
TOTAL	*95.42%*	*4.25%*	*0.33%*	*100.00%*

Figure 2-5 PCBs Contamination Status per Type of Industry, 1st Phase PCBs Inventory



2.6.3 PCBs Contamination Status per Manufacture Year

In terms of samples manufacture year, the project uses the following classification:

- pre-1982
- 1983 – 1992
- 1993 – 2002
- 2003 – 2012

The year 1982 is used as benchmark because before 1982 the usage of PCBs in transformers were still allowed. The project then decided to classify the year of manufacture per 10 years until 2012, which is latest manufacture year of the sampled transformers.

In the 1st phase PCBs inventory sample data, 1,119 (37.14%) samples were manufactured between 2003-2012. The smallest proportion of manufacture year was pre 1983 with 214 samples (7.1%). There were also 16 samples with no record of their manufacture year. The complete proportion can be found in the following table.

Table 2-8 Sampling Proportion per Manufacture Year, 1st Phase PCBs Inventory

Manufacture year	Number of samples (trafo)	Percentage (%)
< 1983	214	7.10%
1983 - 1992	766	25.41%
1993 - 2002	900	29.85%
2003 - 2012	1,119	37.11%
N/A	16	0.53%
TOTAL	*3,015*	*100.00%*

Testing results show that transformers manufactured before 1983 have the highest proportion of contaminated samples (50 ppm ≤ PCBs < 10,000 ppm) with 9.81%. Transformers manufactured between 1993 – 2002 and 1983 – 1992 were the second and third with 4.89% and 4.44%. The newer transformers (2002 – 2012) has the lowest proportion of contaminated samples with 2.68%. There were 6 samples (2.8%) manufactured before 1983 with PCBs concentration above 10,000ppm. These numbers show a rough trend that the probability of PCBs contamination was higher in older transformers, although samples manufactured in 1983 – 1992 and 1993 – 2002 categories do not show significant difference.

Table 2-9 PCBs Contamination Status per Manufacture Year, 1st Phase PCBs Inventory

Manufacture Year	Status			
	Number of samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
< 1983	187	21	6	214
1983 - 1992	732	34	0	766
1993 - 2002	856	42	2	900
2002 - 2012	1,088	30	1	1,119
N/A	14	1	1	16
TOTAL	*2,877*	*128*	*10*	*3,015*

Table 2-10 PCBs Contamination Status Proportion per Manufacture Year, 1st Phase PCBs Inventory

Manufacture Year	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
< 1983	87.38%	9.81%	2.80%	100.00%
1983 - 1992	95.56%	4.44%	0.00%	100.00%
1993 - 2002	95.11%	4.67%	0.22%	100.00%
2002 - 2012	97.23%	2.68%	0.09%	100.00%
N/A	87.50%	6.25%	6.25%	100.00%
TOTAL	*95.42%*	*4.25%*	*0.33%*	*100.00%*

Figure 2-6.1 PCBs Contamination Status per Manufacture Year, 1st Phase PCBs Inventory

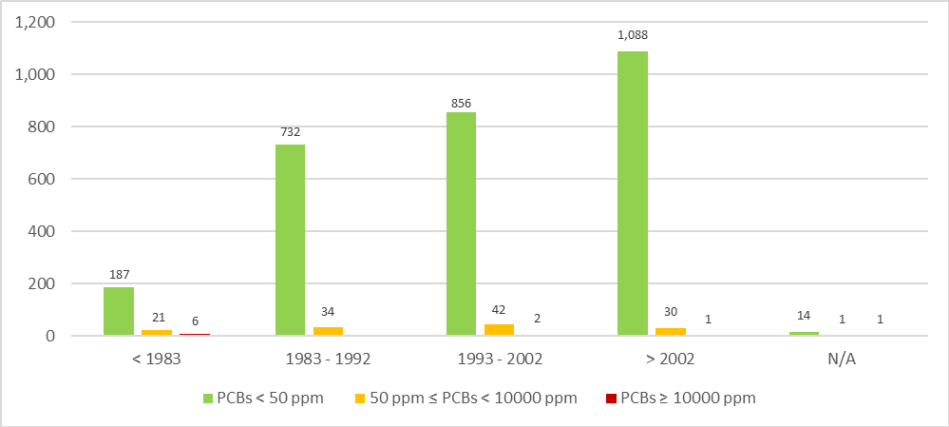
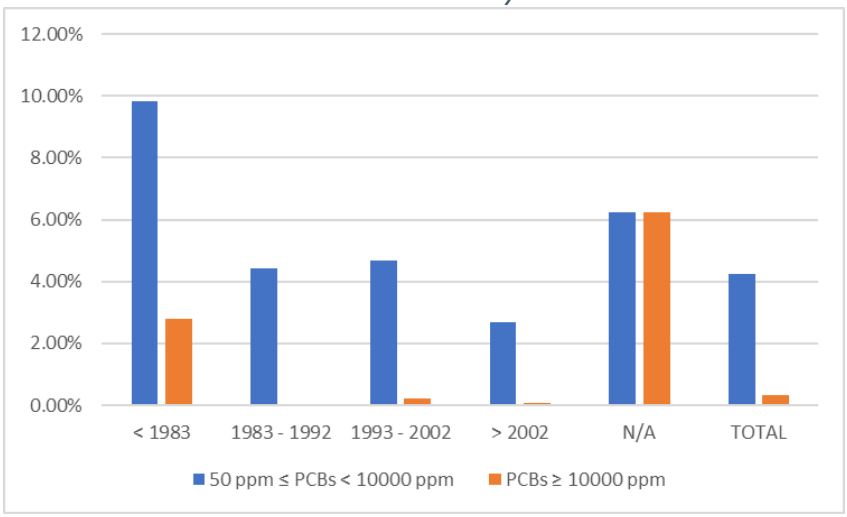


Figure 2-6.2 Percentage of PCBs Contaminated Samples per Manufacture Year, 1st Phase PCBs Inventory



2.6.4 PCBs Contamination Status per Type of Equipment

There were only two types of equipment in the sample data: distribution transformer and power transformer. Overall, the distribution transformer covered 96.75% (2,917 samples) of the sample proportion, and only 2.92% (88 samples) were power transformers.

In terms of PCBs contamination status, there were no power transformer samples contaminated by PCBs, while 138 samples (4.73%) of distribution transformer were contaminated by PCBs.

Table 2-11 Sampling Proportion per Type of Equipment, 1st Phase PCBs Inventory

Type of Equipment	Number of samples (trafo)	Percentage (%)
Distribution Transformer	2,917	96.75%
Power Transformer	88	2.92%
N/A	10	0.33%
Total	*3,015*	*100.00%*

Figure 2-7 Sampling Proportion per Type of Equipment, 1st Phase PCBs Inventory

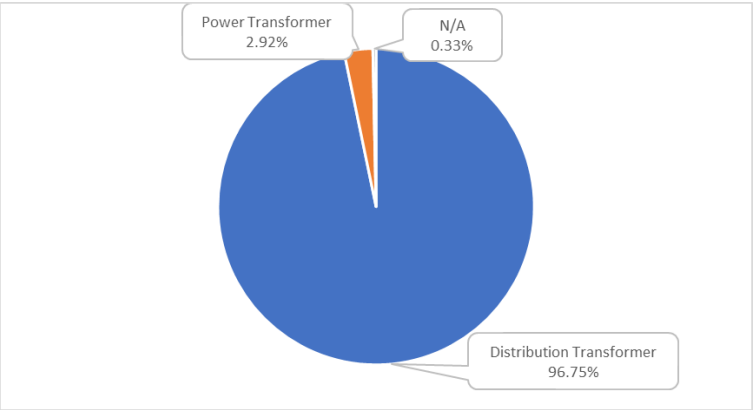


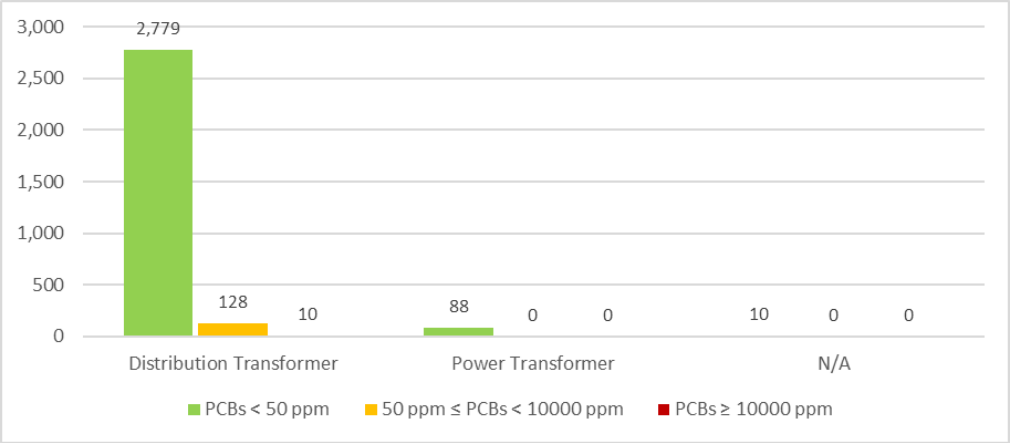
Table 2-12 PCBs Contamination Status per Type of Equipment, 1st Phase PCBs Inventory

Province	Status			
	Number of sample (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Distribution Transformer	2,779	128	10	2,917
Power Transformer	88	0	0	88
N/A	10	0	0	10
TOTAL	*2,877*	*128*	*10*	*3,015*

Table 2-13 PCBs Contamination Status Proportion per Type of Equipment, 1st Phase PCBs Inventory

Province	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Distribution Transformer	95.27%	4.39%	0.34%	100.00%
Power Transformer	100.00%	0.00%	0.00%	100.00%
N/A	100.00%	0.00%	0.00%	100.00%
TOTAL	*95.42%*	*4.25%*	*0.33%*	*100.00%*

Figure 2-8 PCBs Contamination Status per Type of Equipment, 1st Phase PCBs Inventory



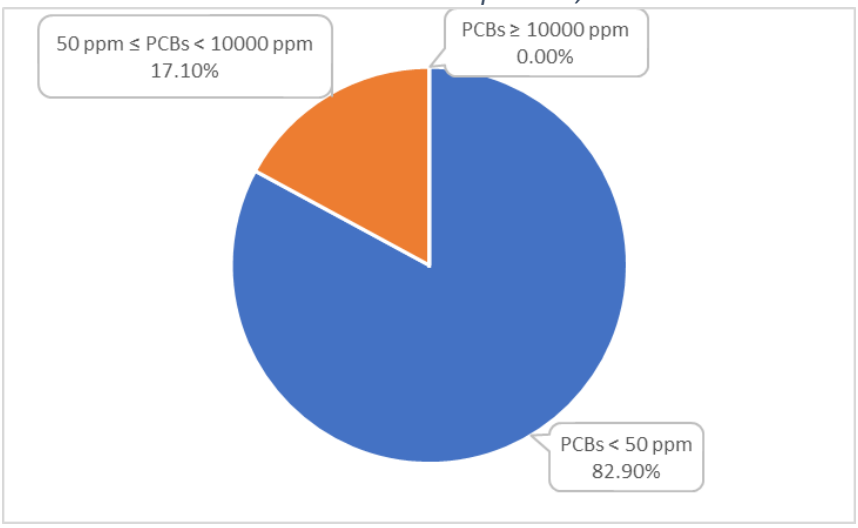
2.7 Descriptive Analysis Results for 2nd Phase of PCBs Inventory

The 2nd phase of PCBs Inventory project took samples from 62 private companies located in 12 provinces in Java and Sumatra, and PT. Perusahaan Listrik Negara (PT. PLN—Indonesia Electrical Company) equipment all over Indonesia. In this report, the data from PLN samples/equipment is not included. The sampling activity (excluding the PLN samples) collected 1,509 samples, and the testing result by using Dexsil showed that there were 258 or 17.1% samples contaminated by PCBs (PCBs contamination number above 50ppm).

Table 2-14 PCBs Contamination Status of 2nd Phase PCBs Inventory Samples

PCB Status	Number of samples (trafo)	Percentage (%)
PCBs < 50 ppm	1,251	82.90%
50 ppm ≤ PCBs < 10,000 ppm	258	17.10%
PCBs ≥ 10,000 ppm	0	0.00%
Total	*1,509*	*100.00%*

Figure 2-9 PCBs Contamination Status Proportion, 2nd Phase PCBs Inventory



This sub-chapter highlights the statistical descriptive analysis of the data collected during the 2nd phase inventory.

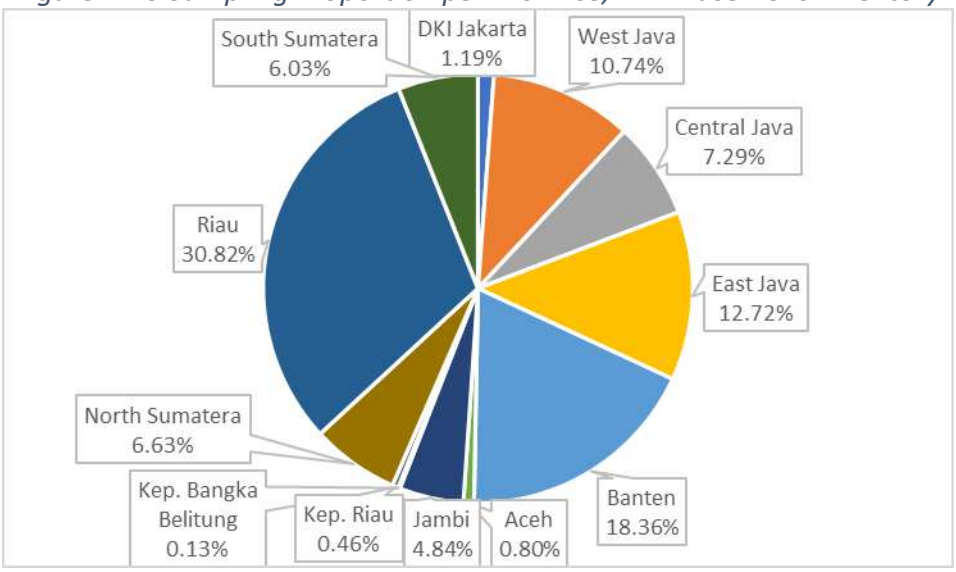
2.7.1 PCBs Contamination Status per Province

The data collected from the 2nd phase of PCBs Inventory were 1,509 transformers in total from seven (7) provinces in Sumatera Island and five (5) provinces in Java island. In terms of sampling proportion, the highest number of samples were taken from Riau Province with 465 samples (30.82%). Banten and East Java were the 2nd and 3rd province with the highest number of samples with 277 (18.36%) and 192 (17.72%) samples, respectively. Sampling proportion per province in more detail can be found in the following table and graph.

Table 2-15 Sampling Proportion per Province, 2nd Phase PCBs Inventory

Province	Number of samples (trafo)	Percentage (%)
DKI Jakarta	18	1.19%
West Java	162	10.74%
Central Java	110	7.29%
East Java	192	12.72%
Banten	277	18.36%
Aceh	12	0.80%
Jambi	73	4.84%
Kep. Bangka Belitung	2	0.13%
Kep. Riau	7	0.46%
North Sumatera	100	6.63%
Riau	465	30.82%
South Sumatera	91	6.03%
TOTAL	*1,509*	100.00%

Figure 2-10 Sampling Proportion per Province, 2nd Phase PCBs Inventory



In terms of PCBs contamination status, DKI Jakarta was the province with the highest proportion of PCBs contaminated samples (50 ppm ≤ PCBs < 10,000 ppm) with 94.44%. Banten and Riau province followed behind with 46.57% and 18.71% respectively. None of the samples from Aceh, Kep. Bangka Belitung and Kep. Riau Province were contaminated with PCBs.

However, the number of samples from DKI Jakarta, Aceh, Kep. Bangka Belitung and Kep. Riau Province were relatively small. Therefore, the samples may be biased and future research may need more samples to produce a more representative result. For DKI Jakarta in particular, all of the 18 samples were collected from 1 (one) company and were manufactured before 1983 or between 1983-1993. More detail breakdown on the PCBs Contamination Status per province can be found in the following tables.

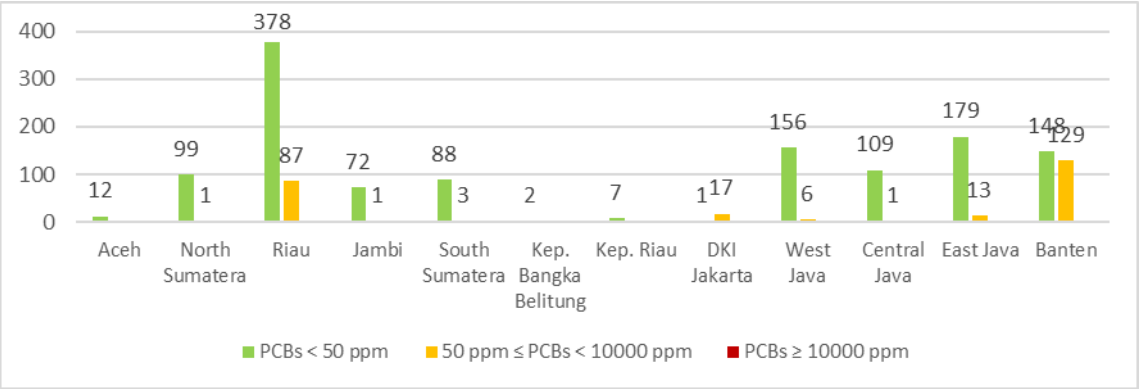
Table 2-16 PCBs Contamination Status per Province, 2nd Phase PCBs Inventory

Province	Status			
	Number of Samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Aceh	12	0	0	12
North Sumatera	99	1	0	100
Riau	378	87	0	465
Jambi	72	1	0	73
South Sumatera	88	3	0	91
Kep. Bangka Belitung	2	0	0	2
Kep. Riau	7	0	0	7
DKI Jakarta	1	17	0	18
West Java	156	6	0	162
Central Java	109	1	0	110
East Java	179	13	0	192
Banten	148	129	0	277
TOTAL	*1,251*	*258*	*0*	*1,509*

Table 2-17 PCBs Contamination Status Proportion per Province, 2nd Phase PCBs Inventory

Province	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Aceh	100.00%	0.00%	0.00%	100.00%
North Sumatera	99.00%	1.00%	0.00%	100.00%
Riau	81.29%	18.71%	0.00%	100.00%
Jambi	98.63%	1.37%	0.00%	100.00%
South Sumatera	96.70%	3.30%	0.00%	100.00%
Kep. Bangka Belitung	100.00%	0.00%	0.00%	100.00%
Kep. Riau	100.00%	0.00%	0.00%	100.00%
DKI Jakarta	5.56%	94.44%	0.00%	100.00%
West Java	96.30%	3.70%	0.00%	100.00%
Central Java	99.09%	0.91%	0.00%	100.00%
East Java	93.23%	6.77%	0.00%	100.00%
Banten	53.43%	46.57%	0.00%	100.00%
TOTAL	*82.90%*	*17.10%*	*0.00%*	*100.00%*

Figure 2-11 PCBs Contamination Status per Province, 2nd Phase PCBs Inventory



2.7.2 PCBs Contamination per Types of Industry

In the 2nd phase of PCBs Inventory project, the sampling was focused on nine (9) energy-intensive industrial sectors/types of industry, which were:

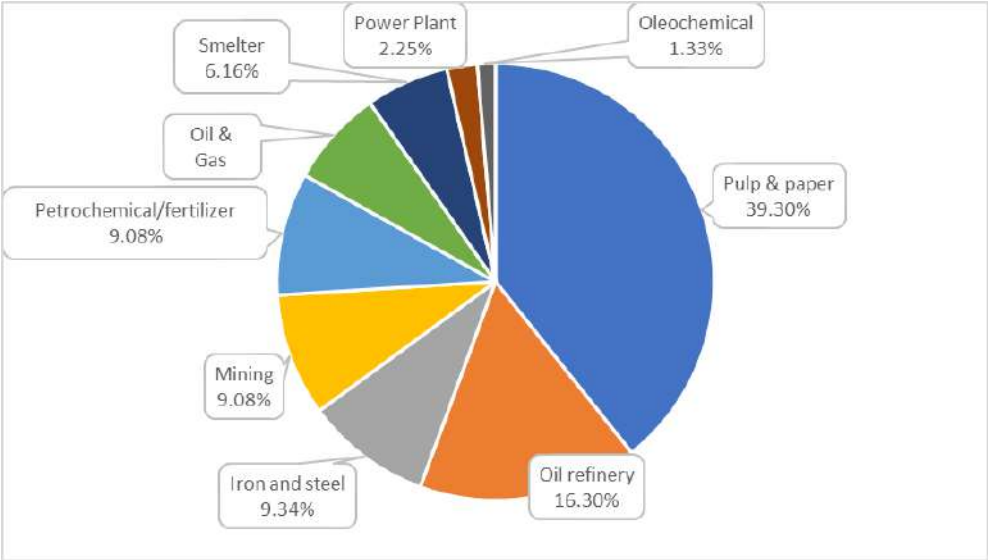
1) pulp and paper
2) oil refinery
3) smelter/metallurgy
4) iron and steel
5) power plant
6) mining
7) oleochemical
8) oil & gas; and
9) petrochemical/fertilizer.

From these nine industry types, the majority of samples (593 samples or 39.30%) was from pulp and paper. Oil refinery was the second industry with the highest number of samples (246 samples or 16.30%), while oleochemical had the least number of samples (20 samples or 1.,33%). A more detail breakdown of sample proportion per types of industry can be found in the table and graph below.

Table 2-18 Sampling Proportion per Type of Industry, 2nd Phase PCBs Inventory

Industry type	Number of samples (trafo)	Percentage (%)
Pulp & paper	593	39.30%
Oil refinery	246	16.30%
Iron and steel	141	9.34%
Mining	137	9.08%
Petrochemical/fertilizer	137	9.08%
Oil & Gas	108	7.16%
Smelter	93	6.16%
Power Plant	34	2.25%
Oleochemical	20	1.33%
TOTAL	*1,509*	*100.00%*

Figure 2-12 Sampling Proportion per Type of Industry, 2nd Phase PCBs Inventory



In terms of PCBs contamination status, the petrochemical/fertilizer sector had the most contaminated sample proportion with 51.82% of samples in this sector were contaminated by PCBs (PCBs concentration between 50ppm and 10,000ppm). Iron and steel sector followed in second place with 34.04%. Oleochemical and power plant sectors both had none of their samples contaminated (0%). However, their relatively low number of samples (20 and 34, respectively, which were also the two lowest numbers of samples amongst the nine sampled sectors) should be taken into consideration.

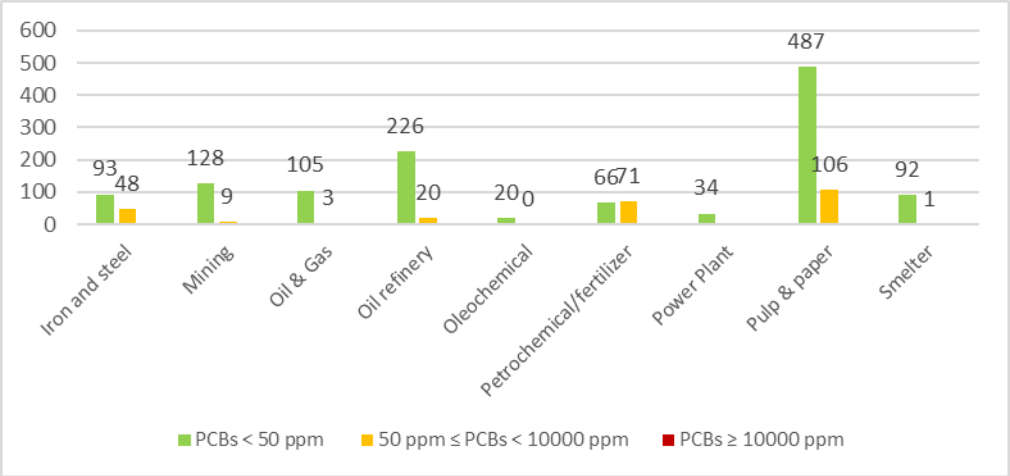
Table 2-19 PCBs Contamination Status per Type of Industry, 2nd Phase PCBs Inventory

Industry type	Status			
	Number of samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Iron and steel	93	48	0	141
Mining	128	9	0	137
Oil & Gas	105	3	0	108
Oil refinery	226	20	0	246
Oleochemical	20	0	0	20
Petrochemical/fertilizer	66	71	0	137
Power Plant	34	0	0	34
Pulp & paper	487	106	0	593
Smelter	92	1	0	93
TOTAL	*1,251*	*258*	*0*	*1,509*

Table 2-20 PCBs Contamination Status Proportion per Type of Industry, 2nd Phase PCBs Inventory

Industry type	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Iron and steel	65.96%	34.04%	0.00%	100.00%
Mining	93.43%	6.57%	0.00%	100.00%
Oil & Gas	97.22%	2.78%	0.00%	100.00%
Oil refinery	91.87%	8.13%	0.00%	100.00%
Oleochemical	100.00%	0.00%	0.00%	100.00%
Petrochemical/fertilizer	48.18%	51.82%	0.00%	100.00%
Power Plant	100.00%	0.00%	0.00%	100.00%
Pulp & paper	82.12%	17.88%	0.00%	100.00%
Smelter	98.92%	1.08%	0.00%	100.00%
TOTAL	*82.90%*	*17.10%*	*0.00%*	*100.00%*

Figure 2-13 PCBs Contamination Status per Type of Industry, 2nd Phase PCBs Inventory



2.7.3 PCBs Contamination Status per Manufacture Year

In terms of samples manufacture year, the 2nd phase PCBs inventory followed the classification used in the 1st phase, which were:

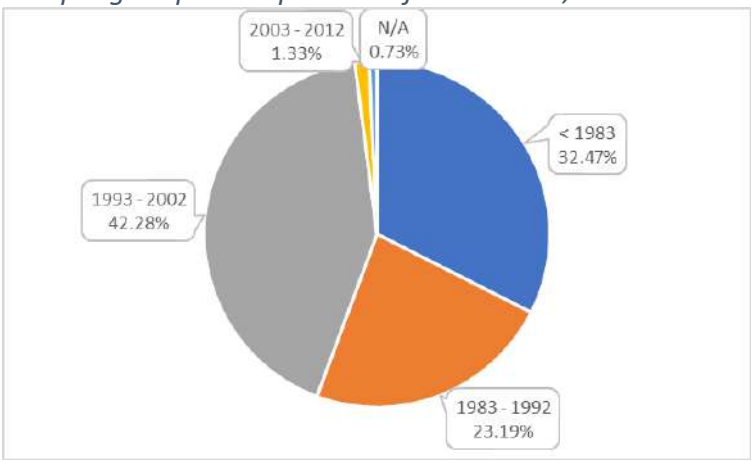
- pre-1982
- 1983 – 1992
- 1993 – 2002
- 2003 – 2012

From the samples collected during the 2nd phase PCBs inventory, most of the samples were manufactured in 1993 – 2002 (638 samples or 42.28%), followed by samples manufactured before 1983 (490 samples or 32.47%). There were only 20 samples (1.33%) manufactured in 2003-2012, and 10 samples with their manufacture year unidentified. The more detailed breakdown can be found in the following table and graph.

Table 2-21 Sampling Proportion per Manufacture Year, 2nd Phase PCBs Inventory

Manufacture year	Number of samples (trafo)	Percentage (%)
< 1983	490	32.47%
1983 - 1992	350	23.19%
1993 - 2002	638	42.28%
2003 - 2012	20	1.33%
N/A	11	0.73%
Total	*1,509*	*100.00%*

Figure 2-14 Sampling Proportion per Manufacture Year, 2nd Phase PCBs Inventory



In terms of PCBs contamination status, transformers manufactured before 1983 had the largest proportion of samples contaminated by PCBs (21.02%). The proportion of samples contaminated by PCBs gradually decreased in younger classifications of manufacture year. Transformers manufactured in 1983 – 1992 had 16.29% of samples contaminated by PCBs, transformers manufactured in 1993 – 2002 had 15.05%, and the youngest sampled transformers (manufactured in 2003 – 2012) had 5%. However, the number of samples manufactured in 2003 – 2012 was only 20, which was significantly lower than the number of samples in the other categories.

The more detailed breakdown can be found in the following tables and graph.

Table 2-22 PCBs Contamination Status per Manufacture Year, 2nd Phase PCBs Inventory

Manufacture year	Status			
	Number of samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
< 1983	387	103	0	490
1983 - 1992	293	57	0	350
1993 - 2002	542	96	0	638
2003 - 2012	19	1	0	20
N/A	10	1	0	11
TOTAL	*1,251*	*258*	*0*	*1,509*

Table 2-23 PCBs Contamination Status Proportion per Manufacture Year, 2nd Phase PCBs Inventory

Manufacture year	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
< 1983	78.98%	21.02%	0.00%	100.00%
1983 - 1992	83.71%	16.29%	0.00%	100.00%
1993 - 2002	84.95%	15.05%	0.00%	100.00%
2003 - 2012	95.00%	5.00%	0.00%	100.00%
N/A	90.91%	9.09%	0.00%	100.00%
TOTAL	*82.90%*	*17.10%*	*0.00%*	*100.00%*

Figure 2-15.1 PCBs Contamination Status per Manufacture Year, 2nd Phase PCBs Inventory

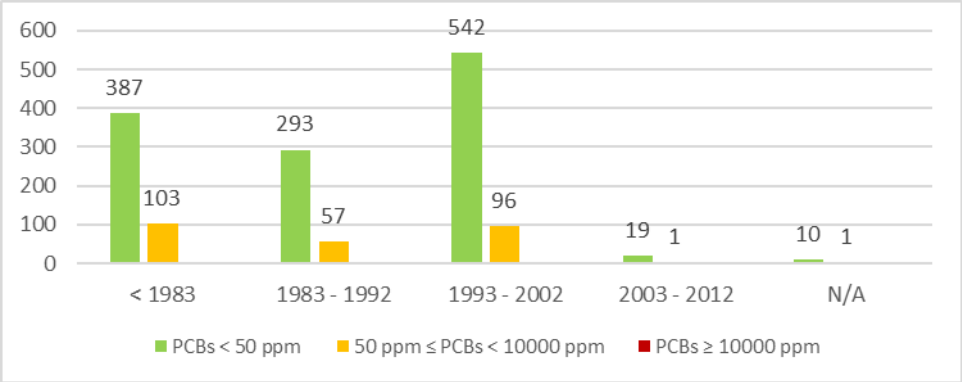
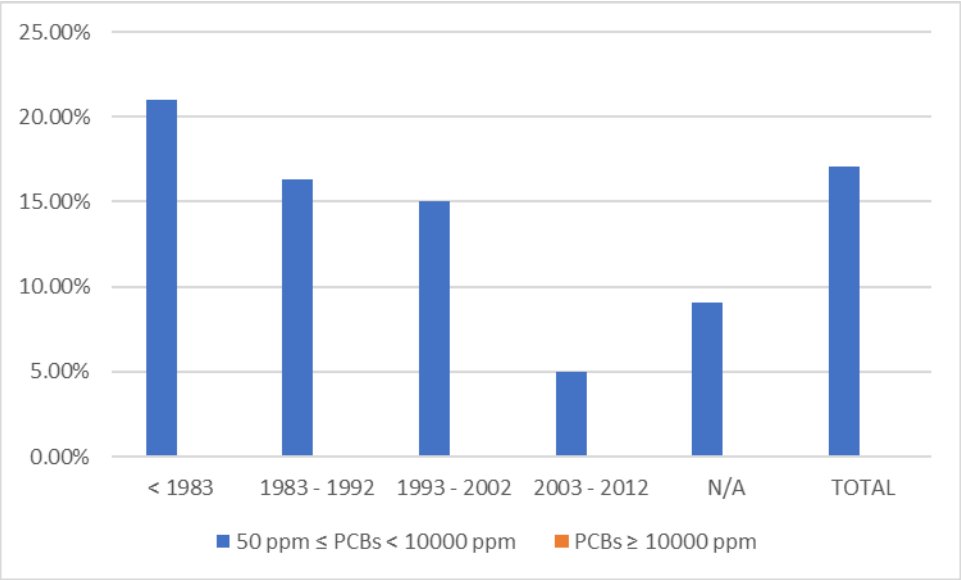


Figure 2-15.2 Percentage of PCBs Contaminated Samples per Manufacture Year, 2nd Phase PCBs Inventory



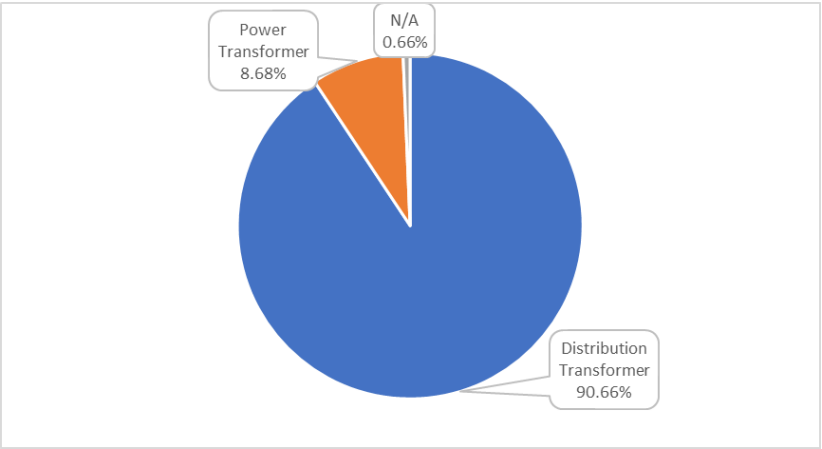
2.7.4 PCBs Contamination Status per Type of Equipment

There were only two types of equipment in the sample data: distribution transformer and power transformer. Overall, the distribution transformer covered 90.66% (1,368 samples) of the sample proportion, while 8.68% (131 samples) were power transformers.

Table 2-24 Sampling Proportion per Type of Equipment, 2nd Phase PCBs Inventory

Type of Equipment	Number of Samples (trafo)	Percentage (%)
Distribution Transformer	1,368	90.66%
Power Transformer	131	8.68%
N/A	10	0.66%
Total	*1,509*	*100.00%*

Figure 2-16 Sampling Proportion per Type of Equipment, 2nd Phase PCBs Inventory



In terms of PCBs contamination status, 2.29% of power transformer samples were contaminated, while in the distribution transformer samples 18.57% were contaminated.

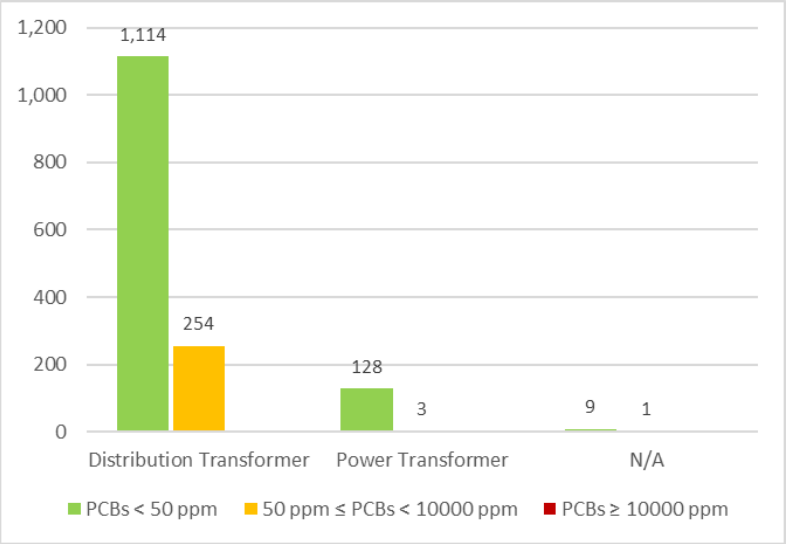
Table 2-25 PCBs Contamination Status per Type of Equipment, 2nd Phase PCBs Inventory

Type of Equipment	Status			
	Number of samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Distribution Transformer	1,114	254	0	1,368
Power Transformer	128	3	0	131
N/A	9	1	0	10
TOTAL	*1,251*	*258*	*0*	*1,509*

Table 2-26 PCBs Contamination Status Proportion per Type of Equipment, 2nd Phase PCBs Inventory

Type of Equipment	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Distribution Transformer	81.43%	18.57%	0.00%	100.00%
Power Transformer	97.71%	2.29%	0.00%	100.00%
N/A	90.00%	10.00%	0.00%	100.00%
TOTAL	*91.27%*	*8.73%*	*0.00%*	*100.00%*

Figure 2-17 PCBs Contamination Status per Type of Equipment, 2nd Phase PCBs Inventory



2.8 Descriptive Analysis Results for Phase 1 & 2 of PCBs Inventory (Combined)

By combining the data from the 1st phase and the 2nd phase of PCBs Inventory projects, the database now contains 4,524 samples, in which 3,015 samples (66.64%) were from the 1st phase inventory and 1,509 samples (33.36%) were from the 2nd phase inventory. In terms of categorization by region (Sumatera and Java), there were 750 samples (16.58%) from Sumatera region and 3,774 (83.42%) from Java region.

Overall, the combined testing results showed that 396 samples (8.75%) were contaminated by PCBs and the remaining 4,128 samples (91.25%) were not contaminated by PCBs (PCBs concentration less than 50ppm). As mentioned in the previous sub-chapters (sub-chapter 2.3 and 2.4), 4.58% of the samples from 1st phase were contaminated by PCBs while 17.1% of samples from the 2nd phase inventory were contaminated. By region, 12.27% of samples from Sumatera were contaminated while 8.45% of samples from Java region were contaminated.

More detail breakdown can be found in the following tables and graph.

Table 2-27 PCBs Contamination Status of Combined PCBs Inventory Database

PCB Status	Number of samples (trafo)	Percentage (%)
PCBs < 50 ppm	4,128	91.25%
50 ppm ≤ PCBs < 10,000 ppm	386	8.53%
PCBs ≥ 10,000 ppm	10	0.22%
Total	*4,524*	*100.00%*

Figure 2-18 PCBs Contamination Status of Combined PCBs Inventory Database

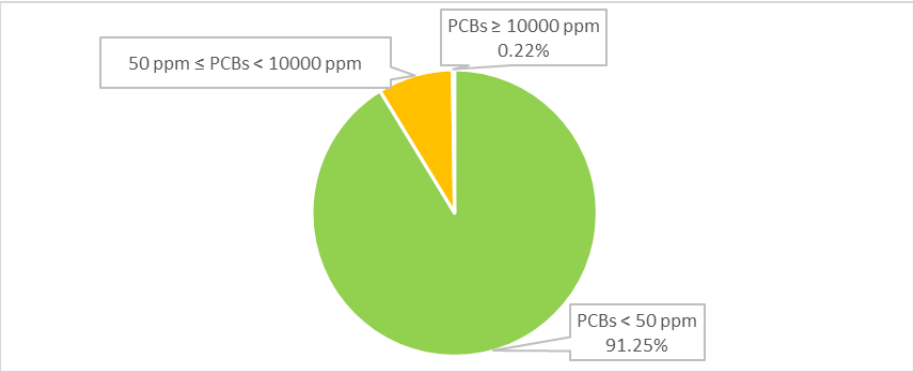


Table 2-28.1 PCBs Contamination Status per Inventory Phase, Combined PCBs Inventory Database

Inventory Phase	PCBs Contamination Status	Number of Samples (trafo)	Percentage (%)
Sample 2016 (1st Inventory)	PCBs < 50 ppm	2,877	95.42%
	50 ppm ≤ PCBs < 10,000 ppm	128	4.25%
	PCBs ≥ 10,000 ppm	10	0.33%
	Total Sample 2016	*3,015*	*66.64%*
Sample 2020 (2nd Inventory)	PCBs < 50 ppm	1,251	82.90%
	50 ppm ≤ PCBs < 10,000 ppm	258	17.10%
	PCBs ≥ 10,000 ppm	0	0.00%
	Total Sample 2020	*1,509*	33.36%
TOTAL		*4,524*	*100.00%*

Table 2-28.2 PCBs Contamination Status per Region, Combined PCBs Inventory Database

Region	PCBs Contamination Status	Number of samples (trafo)	Percentage (%)
Sumatera	PCBs < 50 ppm	658	87.73%
	50 ppm ≤ PCBs < 10,000 ppm	92	12.27%
	PCBs ≥ 10,000 ppm	0	0.00%
	Total Sample Sumatera	*750*	*16.58%*
Java	PCBs < 50 ppm	3,470	91.94%
	50 ppm ≤ PCBs < 10,000 ppm	294	7.79%
	PCBs ≥ 10,000 ppm	10	0.66%
	Total Sample Java	*3,774*	83.42%
TOTAL		*4,524*	*4,524*

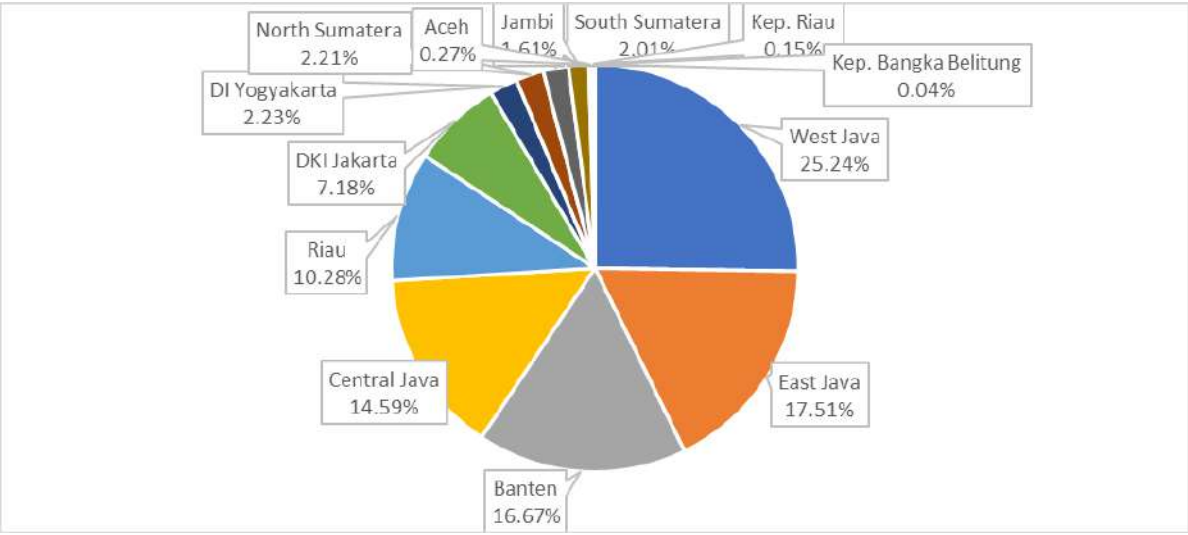
2.8.1 PCBs Contamination Status per Province

From the combined database, it can be seen that the highest number of samples was taken from West Java Province (1,142 samples or 25.24%), followed by East Java (792 samples or 17.51%) and Banten Province (754 or 16.67%). There was only one province from Sumatera area (Riau Province with 465 samples or 10.28%) in the top five of provinces where samples were taken. In total, the samples were taken from thirteen (13) provinces in Sumatera and Java area.

Table 2-29 Sample Proportion per Province, Combined PCBs Inventory Database

Province	Number of samples (trafo)	Percentage (%)
West Java	1,142	25.24%
East Java	792	17.51%
Banten	754	16.67%
Central Java	660	14.59%
Riau	465	10.28%
DKI Jakarta	325	7.18%
DI Yogyakarta	101	2.23%
North Sumatera	100	2.21%
South Sumatera	91	2.01%
Jambi	73	1.61%
Aceh	12	0.27%
Kep. Riau	7	0.15%
Kep. Bangka Belitung	2	0.04%
TOTAL	*4,524*	*100.00%*

Figure 2-19 Sample Proportion per Province, Combined PCBs Inventory Database



In terms of PCBs contamination, Banten (19.63%), Riau (18.71%) and DKI Jakarta (12.31%) were the three provinces with the largest proportions of samples contaminated by PCBs. Aceh, Kep. Bangka Belitung and Kep. Riau Provinces all had 0% of samples contamination by PCBs, however their relatively small number of samples should be taken into consideration. More details on this aspect can be found in the following tables and graph.

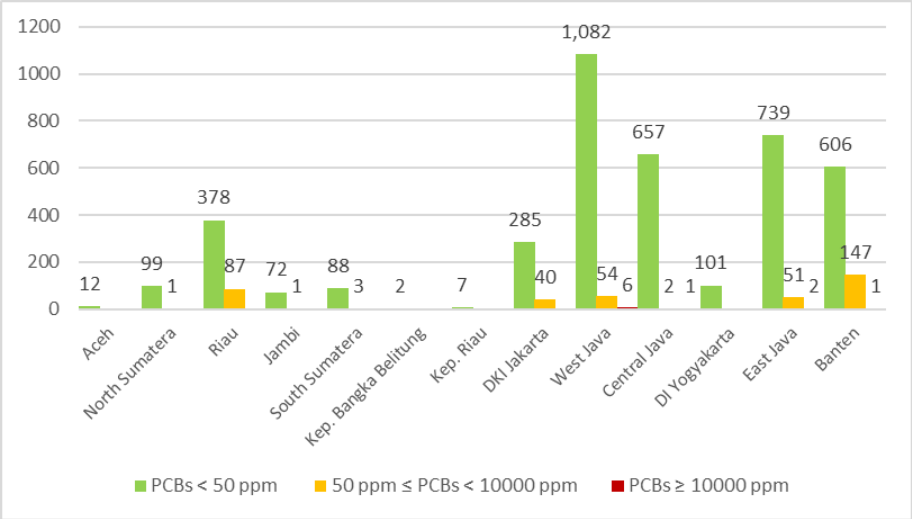
Table 2-30 PCBs Contamination Status per Province, Combined PCBs Inventory Database

Province	Status			
	Number of Samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Aceh	12	0	0	12
North Sumatera	99	1	0	100
Riau	378	87	0	465
Jambi	72	1	0	73
South Sumatera	88	3	0	91
Kep. Bangka Belitung	2	0	0	2
Kep. Riau	7	0	0	7
DKI Jakarta	285	40	0	325
West Java	1,082	54	6	1,142
Central Java	657	2	1	660
DI Yogyakarta	101	0	0	101
East Java	739	51	2	792
Banten	606	147	1	754
TOTAL	***4,128***	***386***	***10***	***4,524***

Table 2-31 PCBs Contamination Status Proportion per Province, Combined PCBs Inventory Database

Province	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Aceh	100.00%	0.00%	0.00%	100.00%
North Sumatera	99.00%	1.00%	0.00%	100.00%
Riau	81.29%	18.71%	0.00%	100.00%
Jambi	98.63%	1.37%	0.00%	100.00%
South Sumatera	96.70%	3.30%	0.00%	100.00%
Kep. Bangka Belitung	100.00%	0.00%	0.00%	100.00%
Kep. Riau	100.00%	0.00%	0.00%	100.00%
DKI Jakarta	87.69%	12.31%	0.00%	100.00%
West Java	94.75%	4.73%	0.53%	100.00%
Central Java	99.55%	0.30%	0.15%	100.00%
DI Yogyakarta	100.00%	0.00%	0.00%	100.00%
East Java	93.31%	6.44%	0.25%	100.00%
Banten	80.37%	19.50%	0.13%	100.00%
TOTAL	***91.25%***	***8.53%***	***0.22%***	***100.00%***

Figure 2-20 PCBs Contamination Status per Province, Combined PCBs Inventory Database



2.8.2 PCBs Contamination per Type of Industry

There was a difference in terms of industry classification between the 1st phase and the 2nd phase PCBs Inventory projects. The 1st phase inventory project did not use particular types of industry as focus for sampling, resulted in a wide variety of industry sectors in the sample database. Therefore, the analysis for the 1st phase was done using industry classification based on Indonesia's Economic Census 2016 (IEC 2016) document. By using the IEC 2016 as reference, Petrolab managed to re-categorized the samples from the 1st phase inventory into five (5) sectors/types of industry in Indonesia, which were as follow:

1. Processing industry/manufacture *(Industri pengolahan*)
2. Mining and extraction (*Pertambangan dan penggalian*)
3. Electricity supply using gas or steam (*Pengadaan listrik gas/uap air panas*)
4. Accommodation, food and beverage (*Penyediaan akomodasi dan makan minum*)
5. Wholesale and retail trade (*Perdagangan besar dan eceran*)

Outside these five main types of industry, there were 90 samples from the 1st phase inventory with a large variety of industry types which were then classified as *Industri lainnya* (other industries).

For the 2nd phase of PCBs Inventory project, the sampling was focused on nine (9) energy-intensive industrial sectors/types of industry, which were:

1) pulp and paper
2) oil refinery
3) smelter/metallurgy
4) iron and steel
5) power plant
6) mining
7) oleochemical
8) oil & gas; and
9) petrochemical/fertilizer.

In combining data from the 1st phase and 2nd phase of PCBs Inventory project by types of industry, Petrolab needed to use one set of industry classification which can accommodate samples from both inventory phases. Considering that the industry sectors sampled for the 2nd phase inventory were more focused/specific compared to the 1st phase, not all samples from the 1st phase inventory can be accommodated if the integration of the two datasets used the industry classification of the 2nd phase inventory. Therefore, Petrolab decided to use the IEC 2016 document as the reference for industry classification of the combined database. Consequently, the samples from 2nd phase inventory were then re-categorized based on the five (5) types of industries used for the 1st phase inventory samples. As a result, the samples from the 2nd phase inventory were accommodated by three (3) industry types in the IEC 2016 classification system, which were:

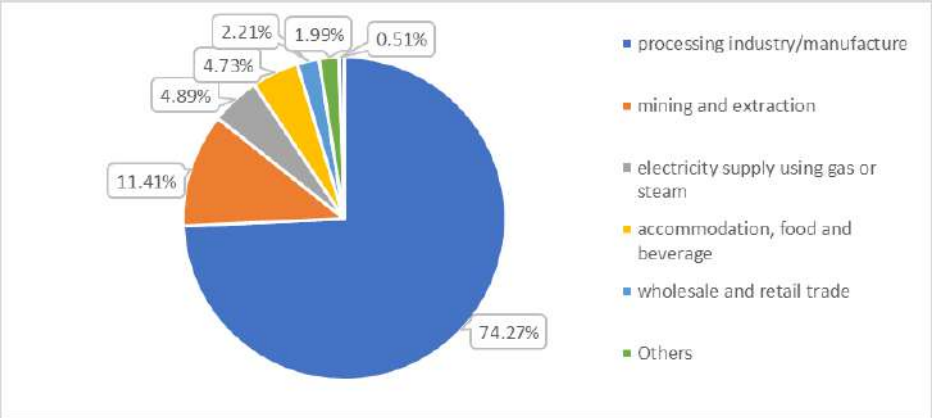
1. Processing industry/manufacture *(Industri pengolahan*)
2. Mining and extraction (*Pertambangan dan penggalian*)
3. Electricity supply using gas or steam (*Pengadaan listrik gas/uap air panas*)

From the total of 4,524 samples (combined database from the 1st and 2nd phase inventory projects), the majority of samples were from the *Industri pengolahan* (processing industry/manufacture) with 3,360 samples or 74.27%. *Pertambangan dan penggalian* (mining and extraction) had the second highest number of samples with 516 samples (11.41%). The detail breakdown can be found in the following tables and graph.

Table 2-32 Sample Proportion per Type of Industry, Combined PCBs Inventory Database

Industry type	Number of Samples (trafo)	Percentage (%)
processing industry/manufacture	3,360	74.27%
mining and extraction	516	11.41%
electricity supply using gas or steam	221	4.89%
accommodation, food and beverage	214	4.73%
wholesale and retail trade	100	2.21%
Others	90	1.99%
N/A	23	0.51%
TOTAL	*4,524*	*100.00%*

Figure 2-21 Sample Proportion per Type of Industry, Combined PCBs Inventory Database



In terms of PCBs contamination, the *Industri Pengolahan* (processing industry/manufacture) was the sector with the highest proportion of its samples contaminated by PCBs with 10%. This is followed by *Pertambangan dan Penggalian* (mining and extraction) with 6.59% and *Penyediaan Akomodasi dan Makan Minum* (accommodation, food and beverage) with 5.61%. More detail breakdown can be found in the following tables and graph.

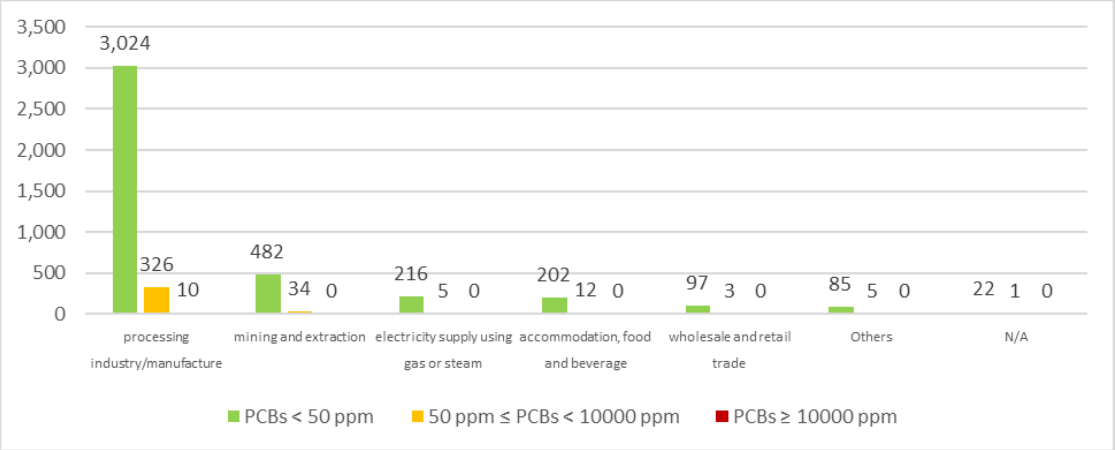
Table 2-33 PCBs Contamination Status per Type of industry, Combined PCBs Inventory Database

Industry type	Status			
	Number of Samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
processing industry/manufacture	3,024	326	10	3,360
mining and extraction	482	34	0	516
electricity supply using gas or steam	216	5	0	221
accommodation, food and beverage	202	12	0	214
wholesale and retail trade	97	3	0	100
Others	85	5	0	90
N/A	22	1	0	23
TOTAL	*4,128*	*386*	*10*	*4,524*

Table 2-34 PCBs Contamination Status Proportion per Type of industry, Combined PCBs Inventory Database

Industry type	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
processing industry/manufacture	90.00%	9.70%	0.30%	100.00%
mining and extraction	93.41%	6.59%	0.00%	100.00%
electricity supply using gas or steam	97.74%	2.26%	0.00%	100.00%
accommodation, food and beverage	94.39%	5.61%	0.00%	100.00%
wholesale and retail trade	97.00%	3.00%	0.00%	100.00%
Others	94.44%	5.56%	0.00%	100.00%
N/A	95.65%	4.35%	0.00%	100.00%
TOTAL	*91.25%*	*8.53%*	*0.22%*	*100.00%*

Figure 2-22 PCBs Contamination Status Proportion per Type of industry, Combined PCBs Inventory Database



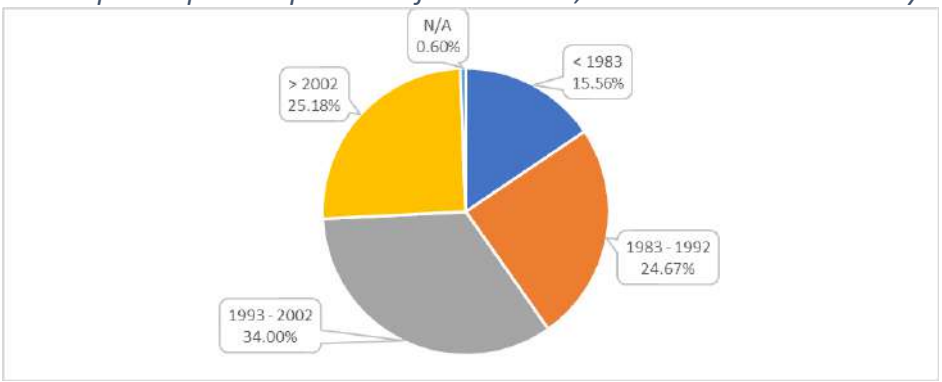
2.8.3 PCBs Contamination Status per Manufacture Year

From the combined database, it can be seen that the highest number of samples was manufactured between 1993 – 2002 (1,538 samples or 34%). The proportion of samples manufactured after 2002 and between 1983 – 1992 were similar with 25.18% and 24.67% respectively. Samples manufactured before 1983 took the smallest proportion with 15.56%.

Table 2-35 Sample Proportion per Manufacture Year, Combined PCBs Inventory Database

Manufacture year	Number of Samples (trafo)	Percentage (%)
< 1983	704	15.56%
1983 - 1992	1,116	24.67%
1993 - 2002	1,538	34.00%
> 2002	1,139	25.18%
N/A	27	0.60%
Total	***4,524***	***100.00%***

Figure 2-23 Sample Proportion per Manufacture Year, Combined PCBs Inventory Database



In terms of PCBs contamination status, the analysis result for the combined database was consistent with the analysis result for the 1st and 2nd phase inventory samples, in which the category of transformers manufactured before 1983 had the highest

proportion of its samples contaminated by PCBs with 18.46%. The categories of transformers manufacture between 1993-2002 and 1983-1993 had relatively similar proportion of samples contaminated by PCBs with 9.1% and 8.15% respectively. The category of transformers manufactured after 2002 had the least proportion of its samples contaminated by PCBs with 2.81%. Detail breakdown can be found in the following tables and graph.

Table 2-36 PCBs Contamination Status per Manufacture Year, Combined PCBs Inventory Database

Manufacture year	Status			
	Number of Samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
< 1983	574	124	6	704
1983 - 1992	1,025	91	0	1,116
1993 - 2002	1,398	138	2	1,538
> 2002	1,107	31	1	1,139
N/A	24	2	1	27
TOTAL	*4,128*	*386*	*10*	*4,524*

Table 2-37 PCBs Contamination Status Proportion per Manufacture Year, Combined PCBs Inventory Database

Manufacture year	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
< 1983	81.53%	17.61%	0.85%	100.00%
1983 - 1992	91.85%	8.15%	0.00%	100.00%
1993 - 2002	90.90%	8.97%	0.13%	100.00%
> 2002	97.19%	2.72%	0.09%	100.00%
N/A	88.89%	7.41%	3.70%	100.00%
TOTAL	*91.25%*	*8.53%*	*0.22%*	*100.00%*

Figure 2-24.1 PCBs Contamination Status per Manufacture Year, Combined PCBs Inventory Database

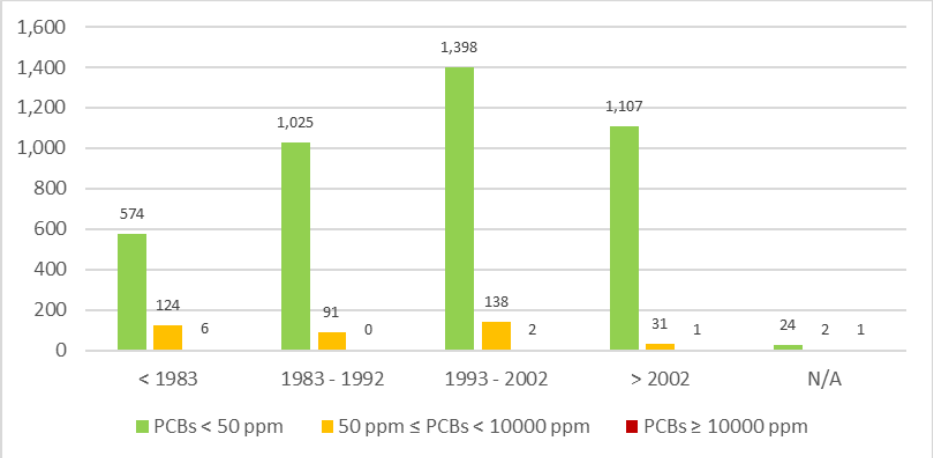
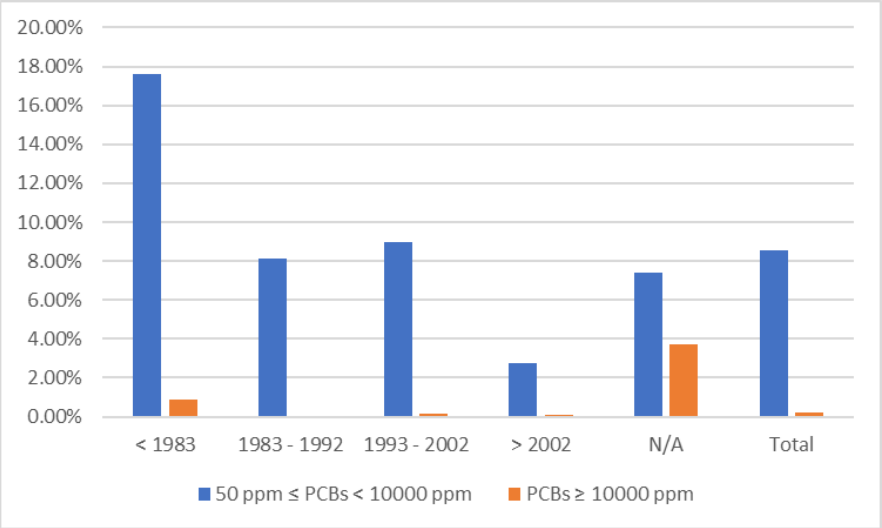


Figure 2-24.2 Percentage of PCBs Contaminated Samples per Manufacture Year, Combined PCBs Inventory Database



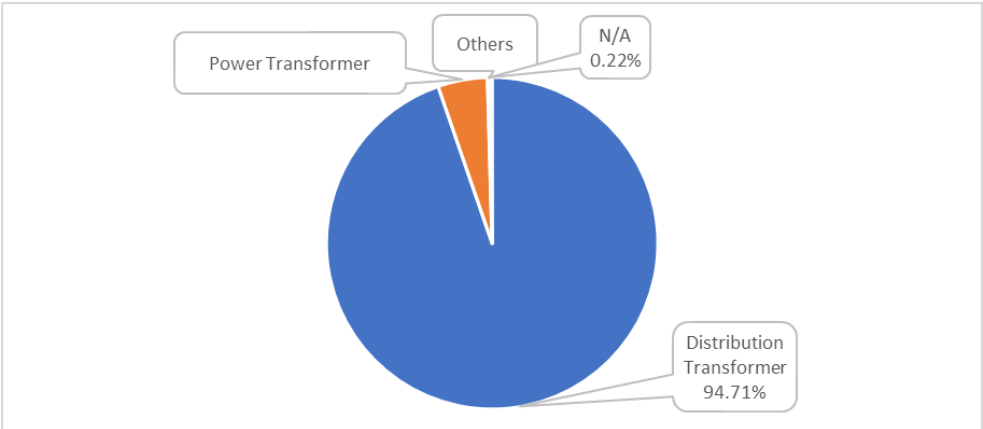
2.8.4 PCBs Contamination Status per Type of Equipment

From the combined database, distribution transformer covered the majority of the samples with 94.71% (4,285 samples) of the sample proportion, while 4.84% (219 samples) were power transformers.

Table 2-38 Sample Proportion per Manufacture Year, Combined PCBs Inventory Database

Type of Equipment	Number of Samples (trafo)	Percentage (%)
Distribution Transformer	4,285	94.71%
Power Transformer	219	4.84%
Others	10	0.22%
N/A	10	0.22%
Total	*4,524*	*100.00%*

Figure 2-25 Sample Proportion per Manufacture Year, Combined PCBs Inventory Database



In terms of PCBs contamination status, 1.37% of power transformer samples were contaminated, while in the distribution transformer samples 9.14% were contaminated.

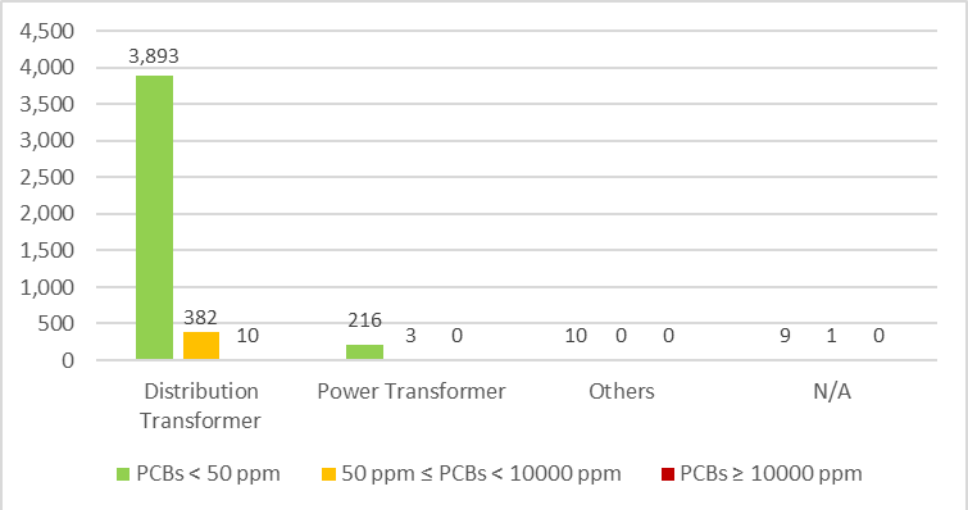
Table 2-39 PCBs Contamination Status per Type of Equipment, Combined PCBs Inventory Database

Type of Equipment	Status			
	Number of Samples (trafo)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Distribution Transformer	3,893	382	10	4,285
Power Transformer	216	3	0	219
Others	10	0	0	10
N/A	9	1	0	10
Total	*4,128*	*386*	*10*	*4,524*

Table 2-40 PCBs Contamination Status Proportion per Type of Equipment, Combined PCBs Inventory Database

Type of Equipment	Status			
	Percentage (%)			
	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	Total
Distribution Transformer	90.85%	8.91%	0.23%	100.00%
Power Transformer	98.63%	1.37%	0.00%	100.00%
Others	100.00%	0.00%	0.00%	100.00%
N/A	90.00%	10.00%	0.00%	100.00%
Total	*91.25%*	*8.53%*	*0.22%*	*100.00%*

Figure 2-26 PCBs Contamination Status Proportion per Type of Equipment, Combined PCBs Inventory Database



3 Analysis and Findings

From the factor analysis and descriptive analysis done, there were some findings and insights that can be discussed in this chapter, which were as follow:

- The results of factor analysis showed that "manufacture year" as the only factor that correlates with PCBs contamination. From the combined database (1st phase PCBs inventory data and 2nd phase PCBs inventory data), it can be seen that the category of transformers manufactured before 1983 had the highest proportion of samples contaminated by PCBs with 18.46%. The categories of transformers manufacture between 1993-2002 and 1983-1993 had relatively similar proportion of samples contaminated by PCBs with 9.1% and 8.15% respectively. The category of transformers manufactured after 2002 had the least proportion of its samples contaminated by PCBs with 2.81%.

  Although the contamination data per manufacture year validated the factor analysis result, and showed that the older transformers were more likely to be contaminated by PCBs, it also showed that the newer transformers (manufactured after 2002) still had samples contaminated by PCBs. Moreover, the transformers manufactured between 1993-2002 and 1983-1993 had relatively similar proportion of samples contaminated by PCBs, with the 1993-2002 category actually showed slightly higher proportion of contamination.

  Ideally, newer transformers should not be contaminated by PCBs, as they were manufactured after the utilisation of PCBs was prohibited in 1983. Hence, there must be another factor that caused the contamination.

  Because there was lack of information regarding the trade name of insulating oil used in the samples (the number of samples with this information was too little), this research was unable to observe the correlation of this factor in PCBs contamination. However, from the database, from the small number of samples with information regarding the trade name of the oil, there were only three (3) samples that used an oil brand (Askarel) that was included in the MoEF Ministerial Decree No. P29/2020 (in the list of prohibited oil due to PCBs utilisation). Therefore, this showed that PCBs contamination also occurred in samples that used the non-PCBs oil brands.

  With all of the findings above, there was a strong indication that PCBs contamination in transformers in Indonesia was caused by cross-contamination during purification or reclamation process.

  This is in-line with the findings in one of the United Nations Environment Programme/ UNEP's publication in May 2002: "PCBs Transformers and Capacitors: From Management to Reclassification and Disposal"[1] in page 30 which stated: "It has been found in many countries that there are two different reasons why a transformer may contain PCBs. The first is that the transformer was designed and built to be used with a PCBs oil. These are the cases that have been considered up until now in this publication. However, experience

[1] link to the publication can be found here: https://wedocs.unep.org/bitstream/handle/20.500.11822/32457/PCB.pdf?sequence=1&isAllowed=y

has shown that many transformers sold, or labelled, as non-PCBs transformers can in fact contain PCBs. This is because many transformers using conventional oil have been cross-contaminated by PCBs. In Europe, this figure may be as high as 45 per cent. The reason is that the facilities used many years ago for filling transformers were often employed both for PCBs oils, and for other, non-PCBs oils. Cross-contamination thus occurred and a transformer marked as a conventional oil transformer may contain well above 0.005 per cent (50 ppm) of PCBs, which is the ultimate threshold specified in Annex A of the Stockholm Convention. In such cases retrofilling is a practical method of reducing PCBs levels to below 0.005 per cent."

- During the assessment of the database for both the 1st and 2nd phase PCBs Inventory, it was found that the database is lacking information related to maintenance of the transformers and the tradename of the transformers oil being used. A proper maintenance recording or data (particularly purification and retro-filling) should hold a key role to better analyse the causes of PCBs contamination to transformer oil in the future.

- In a more-focused sampling activity to types of industries that were expected to have more PCBs contaminated transformers (in 2nd phase PCBs inventory), the proportion of PCBs contaminated transformers was 17.10%. However, if involving broader range of economic sectors in Indonesia (combined 1st phase and 2nd phase PCB Inventory), the proportion of PCBs contaminated transformers was 8.75%. This was considered more representative to provide a more general context for Indonesia's condition.

4 Data Extrapolation

In regards to providing input for the arrangement of a nation-scale PCBs Management Plan, the project extrapolated the samples dataset from the 1st and 2nd phase of PCBs inventory to estimate the population number of transformers in Indonesia and its characteristics per region. In doing so, the project also uses the Indonesia's Economic Census 2016 (EC-2016) document combined with the existing database of industries as base data.

Data extrapolation was needed due to the lack of database of transformers in Indonesia that can provide information regarding population number of transformers and their general characteristics. Meanwhile, this information is needed to arrange the PCBs Management Plan and Action Plan.

4.1 Approach Used

The extrapolation was conducted to estimate:

1. The total number of transformers in Indonesia
2. The general characteristics of transformers population in Indonesia regionally, based on types of industry, PCBs contamination status, manufacture year and power rating
3. Volume of PCBs contaminated transformers oil in nation-scale
4. Total weight of PCBs contaminated transformers in nation-scale

The extrapolation was heavily based on the results of statistical descriptive analysis combined with the medium to large companies' census data contained in Indonesia's EC-2016 document. The steps of extrapolation analysis were divided into two main stages which were as follow:

- <u>Stage 1, extrapolating transformers population and estimating population characteristics:</u>
  1. Identify the population/number of medium to large companies per province Indonesia for the five (5) main types of industry analysed by the project. This data was contained in the Indonesia's Economic Census 2016 (EC-2015) document. The types of industry used in the analysis were as follow:
     a. Processing industry/manufacture (*Industri pengolahan*)
     b. Mining and extraction (*Pertambangan dan penggalian*)
     c. Electricity supply using gas or steam (*Pengadaan listrik gas/uap air panas*)
     d. Accommodation, food and beverage (*Penyediaan akomodasi dan makan minum*)
     e. Wholesale and retail trade (*Perdagangan besar dan eceran*)
  2. Identify the average number of transformers owned by each company per types of industry. This step assumed that companies in different types of industry will need (and owned) different numbers of transformers.
  3. Estimate the total number of transformers by multiplying the number of companies per type of industry per province (data from step no. 1) with the

average numbers of transformers owned by each company per type of industry (result from step no. 2). This step resulted in estimation of total population number of transformers per province per type of industry. Estimation of total population number of transformers for national-scale was also produced by adding all of the transformer numbers from all provinces.

4. Estimate the number of transformers per PCBs contamination category per province. This was done by using the proportion of PCBs contamination categories as produced in the PCBs inventory database descriptive analysis, multiplied with the estimated number of transformers per province (produced in step no. 3).
5. Estimate the number of transformers per PCBs manufacture year per province. This was done by using the proportion of PCBs manufacture year as produced in the PCBs inventory database descriptive analysis, multiplied with the estimated number of transformers per province (produced in step no. 3).

- <u>Stage 2, estimating oil volume and equipment weight of contaminated transformers:</u>
    1. Considering that oil volume and equipment weight depended on the size of transformers, this phase relied heavily on estimating the number of transformers per power rating categories. In the PCBs inventory database, power rating was the variable that mostly reflected transformers' size. Therefore, the first step in this stage was to estimate the number of transformers per power rating category per province. This was done by using the proportion of transformers per power rating categories. As the PCBs inventory sample database varied highly between provinces in terms of representativeness per power rating categories, this power rating proportion was not included in the database descriptive analysis. This proportion was then calculated based on the whole sample database, and then applied to the estimated number of transformers per province (produced in stage 1 step 3).
    2. Estimate the nation-scale volume of PCBs contaminated transformers oil using the following steps:
        a. Estimate the proportion of samples contaminated by PCBs per power rating category. This was done by identifying the number of samples in each power rating category which was contaminated by PCBs with concentration ≥ 50ppm.
        b. Identify the sample proportion per contamination category in the contaminated samples group. This means the proportion of samples with 50 ppm ≤ PCBs < 10,000 ppm and samples with PCBs ≥ 10,000 ppm in the group of samples contaminated by PCBs (concentration ≥ 50ppm).
        c. Estimate the number of contaminated transformers per power rating category per province by multiplying the proportion of PCBs contamination per power rating category with the number of transformers per power rating per provinces (produced in stage 2 step no.1)
        d. Estimate the average volume of oil per transformer in each power rating category. This was done by adding all of oil volume data from all samples in each power rating category, divided by the number of samples in each category.

e. Estimate the volume of oil from contaminated transformers per province by multiplying the number of contaminated transformers per power rating category per province (produced in stage 2 step no. 2c) with the average volume of oil per transformer per power rating category (produced in stage 2 step no. 2d).
f. Estimate the volume of oil from contaminated transformers per contamination status by multiplying the sample proportion per contamination category (produced in stage 2 step no. 2b) with the estimated oil volume from contaminated transformers per province (produced in stage 2 step no. 2d)

3. Estimate the nation-scale equipment weight of PCBs contaminated transformers using the steps analogue/similar with the steps for estimating the volume of PCBs contaminated transformers oil in stage 2 step no.2.

4.2 Assumptions Used and Limitations of Analysis

The analysis on Data Extrapolation was done under the following assumptions and limitations:

- The sample data was only acquired in limited provinces in Java and Sumatera, and therefore extrapolation analysis was more reliable for Java and Sumatera while for outside Java and Sumatera the extrapolated results were estimated (as explained in chapter 3). Direct extrapolation analysis was not applied to other regions outside Sumatera and Java, because the project did not have sample data from those other regions and the surrounding conditions/infrastructure may be different with Sumatera and Java. The analysis used an assumption that the number of transformers in Sumatera-Java regions compared with outside Sumatera-Java will be similar with the proportion of number of companies in Sumatera-Java and outside Sumatera-Java.
- From Indonesia's Economic Census 2016, we found that 83.77% of Medium to Large scale companies in Indonesia is located in Java – Sumatera. The extrapolation uses the assumption that the total number of transformers in Java-Sumatera also covers 83.77% of all transformers in Indonesia.
- Extrapolation was based on finding the average number of transformers per company in each industry type. This number was generated from average number per province. However, there were provinces with inadequate number of samples for particular industry types. For the most part, these provinces were excluded from the analysis, except if there was no other alternative provinces data that could be used.
- The numbers generated from the extrapolation did not include transformers owned by PT PLN. Data from PT PLN can complement the extrapolated number to produce an estimated total number of transformers in Indonesia.
- The numbers generated from the extrapolation should be treated as "minimum number of transformers", because they were generated only from the five (5) main types of industries (categorization based on Indonesia's economic census 2016) that were included in the sampling activities from the 1st and 2nd phase of PCBs inventory. This meant that the generated extrapolation numbers did not include

transformers from other types of industries outside those five (5) sectors. The analysis did not have enough information to estimate the number of transformers from the other types of industry.

4.3 *Estimating the Total Number of Transformers in Indonesia*

In estimating the total number of transformers in Indonesia, the approach taken was to identify the average number of transformers owned by each medium to large company in Indonesia, and then multiply that average number with the number of medium to large companies in Indonesia. The number of medium to large companies in Indonesia data was contained in the Indonesia's Economic Census 2016 (EC-2016). Since the PCBs inventory database only consisted of five (5) economic sectors/types of industry (classification based on EC-2016), then the extrapolation in this analysis was only conducted for these five (5) types of industry, which were:

a. Processing industry/manufacture (*Industri pengolahan*)
b. Mining and extraction (*Pertambangan dan penggalian*)
c. Electricity supply using gas or steam (*Pengadaan listrik gas/uap air panas*)
d. Accommodation, food and beverage (*Penyediaan akomodasi dan makan minum*)
e. Wholesale and retail trade (*Perdagangan besar dan eceran*)

The number of medium to large companies in Indonesia per province per type of industry can be seen in the following table.

Table 4-1 Number of Medium to Large Companies per Province per Type of Industry

Province	Number of Medium to Large Companies					
	Pertambangan dan Penggalian	Industri Pengolahan	Pengadaan Listrik Gas/Uap Air Panas dan Udara Dingin	Perdagangan Besar dan Eceran	Penyediaan Akomodasi dan Penyediaan Makan Minum	Total
Aceh	35	75	29	2,456	85	2,680
Sumatera Utara	31	1,433	74	6,142	420	8,100
Sumatera Barat	60	204	30	3,943	179	4,416
Riau	70	352	46	4,294	248	5,010
Jambi	39	166	9	1,800	89	2,103
Sumatera Selatan	85	284	31	3,165	215	3,780
Bengkulu	33	66	6	988	41	1,134
Lampung	48	466	21	3,773	100	4,408
Kep. Bangka Belitung	78	114	7	737	71	1,007
Kepulauan Riau	30	623	32	2,375	382	3,442
DKI Jakarta	58	2,903	168	21,417	4,600	29,146
Jawa Barat	180	9,194	182	24,448	2,285	36,289
Jawa Tengah	59	5,225	83	17,420	868	23,655
DI Yogyakarta	10	569	8	3,344	397	4,328
Jawa Timur	116	6,967	129	25,412	1,425	34,049

Province	Number of Medium to Large Companies					
	Pertambangan dan Penggalian	Industri Pengolahan	Pengadaan Listrik Gas/Uap Air Panas dan Udara Dingin	Perdagangan Besar dan Eceran	Penyediaan Akomodasi dan Penyediaan Makan Minum	Total
Banten	51	3,684	42	9,266	1,175	14,218
Bali	6	570	29	4,122	1,696	6,423
Nusa Tenggara Barat	19	172	25	2,110	184	2,510
Nusa Tenggara Timur	18	54	20	806	85	983
Kalimantan Barat	59	202	36	1,997	115	2,409
Kalimantan Tengah	65	137	12	1,394	68	1,676
Kalimantan Selatan	106	168	18	2,123	160	2,575
Kalimantan Timur	189	266	33	2,522	259	3,269
Kalimantan Utara	26	50	7	326	20	429
Sulawesi Utara	16	145	22	1,505	152	1,840
Sulawesi Tengah	99	122	22	1,089	55	1,387
Sulawesi Selatan	87	615	62	5,204	400	6,368
Sulawesi Tenggara	59	104	33	1,061	46	1,303
Gorontalo	4	41	5	340	29	419
Sulawesi Barat	6	28	12	327	10	383
Maluku	6	51	14	468	60	599
Maluku Utara	8	13	9	318	19	367
Papua Barat	14	44	21	378	44	501
Papua	8	56	15	798	111	988
Indonesia	**1,778**	**35,163**	**1,292**	**157,868**	**16,093**	**212,194**

Source: Indonesia's Economic Census 2016 data from https://se2016.bps.go.id/umkumb/index.php/site/tabel?tid=23&wid=0 (accessed on 3 August 2020)

Assuming that companies in different types of industry will need (and owned) different numbers of transformers, the next step was to Identify the average number of transformers owned by each company per types of industry. For this purpose, the analysis used the data on total number of transformers owned by sampled companies from the PCBs inventory phase 1 and phase 2 sampling activities. The analysis can be seen in the following table.

Table 4-2 Estimated Average Number of Transformers Owned by Each Company per Type of Industry

Industry type	Province	Number of Sampled Company	Number of Total Trafo in Sampled Company	Estimated Avg Number of Trafo per Company in Sampled Province	Estimated Avg Number of Trafo per company per Industry Type
Industri Pengolahan	East Java	159	1,137	7.15	**5.58**
	West Java	279	1,485	5.32	
	Central Java	200	763	3.82	
	DI Yogyakarta	9	42	4.67	
	Banten	135	832	6.16	
	DKI Jakarta	54	342	6.33	
	Riau	2	376	Number of sampled companies are too small	
	Aceh	1	20		
	Jambi	1	249		
	Kep. Bangka Belitung	1	3		
	Kep. Riau	1	10		
	North Sumatera	3	106		
	South Sumatera	1	21		
Pertambangan dan Penggalian	Banten	1	5	5.00	**442.77**
	Central Java	2	93	46.50	
	East Java	3	104	34.67	
	Kep. Bangka Belitung	1	3	3.00	
	Kep. Riau	1	10	10.00	
	Riau	2	6,685	3,342.50	
	South Sumatera	3	147	49.00	
	West Java	2	103	51.50	
Pengadaan Listrik Gas/Uap Air Panas	West Java	2	205	102.50	**50.94**
	Banten	3	40	13.33	
	Central Java	3	111	37.00	
Penyediaan Akomodasi dan Makan Minum	Banten	5	10	2.00	**2.92**
	Central Java	25	64	2.56	
	DI Yogyakarta	19	43	2.26	
	DKI Jakarta	14	51	3.64	
	East Java	11	37	3.36	
	West Java	21	78	3.71	
Perdagangan Besar dan Eceran	Central Java	10	25	2.50	**3.45**
	DI Yogyakarta	6	20	3.33	
	DKI Jakarta	10	54	5.40	
	East Java	9	23	2.56	
	West Java	1	1		

In Table 4-2, the cells marked with blue colour meant that the number of sampled companies in those provinces for their respective type of industry were too small and may be misleading. Therefore, the data from the blue-marked cells were not included in calculating the average number for their respective type of industry. The cells marked with red colour, which were from the *Pertambangan dan penggalian* (mining and extraction) and the *Pengadaan listrik gas/uap air panas* (electricity supply using gas or steam) sectors, were also considered too small to be used for calculating the average numbers for their respective industry types. However, eventually data from the red-marked cells were used in the calculation because there were no other data alternatives/additions that could be used.

After the average numbers were identified, the next step was to multiply the average numbers with the number of companies, according to province and type of industry. The produced average numbers per industry types can be applied to estimate the number of transformers in Sumatera and Java regions, because they were calculated based on sample data from those regions. However, this may not be applied to other regions outside Sumatera and Java, because the project did not have sample data from those other regions and the surrounding conditions/infrastructure may be different with Sumatera and Java. Therefore, the analysis used an assumption that the number of transformers in Sumatera-Java regions compared with outside Sumatera-Java will be similar with the proportion of number of companies in Sumatera-Java and outside Sumatera-Java.

From Table 4-1, it was identified that the total number of companies in Sumatera-Java was 177,765, while outside Sumatera-Java had a total of 34,429 companies. This means that Sumatera-Java contained 83.77% of all companies in Indonesia, while regions outside Sumatera-Java contained 16.23%. This proportion was assumed to be applicable also for the number of transformers in the two (2) big regions.

Based on this assumption, the estimated number of transformers in Sumatera-Java was treated as 83.77% of the whole transformers population in Indonesia (100%). The number of transformers in region outside Sumatera-Java was then calculated as the remaining 16.23%. The analysis and calculation can be found in the following table (table 4-3).

Table 4-3 Estimated Population Number of Transformers

Province	Pertambangan dan Penggalian		Industri Pengolahan		Pengadaan Listrik Gas/Uap Air Panas dan Udara Dingin		Perdagangan Besar dan Eceran		Penyediaan Akomodasi dan Penyediaan Makan Minum	
	Number of Company	Estimated Number of Trafo (Avg 442.77 per company)	Number of Company	Estimated Number of Trafo (Avg 5.58 per company)	Number of Company	Estimated Number of Trafo (Avg 50.94 per company)	Number of Company	Estimated Number of Trafo (Avg 3.45 per company)	Number of Company	Estimated Number of Trafo (Avg 2.92 per company)
Aceh	35	15,497	75	419	29	1,477	2,456	8,473	85	248
Sumatera Utara	31	13,726	1,433	7,996	74	3,770	6,142	21,190	420	1,226
Sumatera Barat	60	26,566	204	1,138	30	1,528	3,943	13,603	179	523
Riau	70	30,994	352	1,964	46	2,343	4,294	14,814	248	724
Jambi	39	17,268	166	926	9	458	1,800	6,210	89	260
Sumatera Selatan	85	37,635	284	1,585	31	1,579	3,165	10,919	215	628
Bengkulu	33	14,611	66	368	6	306	988	3,409	41	120
Lampung	48	21,253	466	2,600	21	1,070	3,773	13,017	100	292
Kep. Bangka Belitung	78	34,536	114	636	7	357	737	2,543	71	207
Kepulauan Riau	30	13,283	623	3,476	32	1,630	2,375	8,194	382	1,115
DKI Jakarta	58	25,681	2,903	16,199	168	8,558	21,417	73,889	4,600	13,432
Jawa Barat	180	79,699	9,194	51,303	182	9,271	24,448	84,346	2,285	6,672
Jawa Tengah	59	26,123	5,225	29,156	83	4,228	17,420	60,099	868	2,535
DI Yogyakarta	10	4,428	569	3,175	8	408	3,344	11,537	397	1,159
Jawa Timur	116	51,361	6,967	38,876	129	6,571	25,412	87,671	1,425	4,161
Banten	51	22,581	3,684	20,557	42	2,139	9,266	31,968	1,175	3,431
Total Sumatera-Java (83.77%)		**435,243**		**180,374**		**45,693**		**451,881**		**36,734**
Outside Sumatera - Java (16.23%)		**84,297**		**34,934**		**8,850**		**87,519**		**7,114**
Total Indonesia (100%)		**519,539**		**215,308**		**54,543**		**539,400**		**43,848**

From Table 4-3, we can estimate the total number of transformers in Sumatera-Java region is the sum of total number of transformers from all types of industry, resulted in a total number of **1,149,924** transformers. As discussed before, this number was 83.77% of the total transformers in Indonesia. Therefore, the number of transformers in regions outside Sumatera-Java was estimated at **222,714** transformers, and the total number of transformers population in Indonesia was estimated at **1,372,638** transformers.

4.4 General Characteristics of Transformers Population in Indonesia

Based on the estimated population number of transformers in Indonesia by province identified in in Table 4-3, the project analysed the general characteristics of this population. In particular, analysis was conducted to estimate the number of transformers per province based on type of industry, PCBs contamination level/category, manufacture year, and power rating.

4.4.1 Estimating Population Number of Transformers per Province Based on Type of Industry, PCBs Contamination Category and Manufacture Year

The number of transformers per province per type of industry was actually already identified in Table 4-3, which was done by multiplying the average numbers of transformers per company with the number of companies, according to province and type of industry. For clearer view of the produced numbers, and adding the numbers for regions outside Sumatera-Java, can be found in Table 4-4 below.

Table 4-4 Estimated Population Number of Transformers per Province per Industry Type

Province	Estimated Number of Transformers per Industry Type					Total Number of Transformers
	Pertambangan dan Penggalian	Industri Pengolahan	Pengadaan Listrik Gas/Uap Air Panas dan Udara Dingin	Perdagangan Besar dan Eceran	Penyediaan Akomodasi dan Penyediaan Makan Minum	
Aceh	15,497	419	1,477	8,473	248	**26,114**
Sumatera Utara	13,726	7,996	3,770	21,190	1,226	**47,908**
Sumatera Barat	26,566	1,138	1,528	13,603	523	**43,359**
Riau	30,994	1,964	2,343	14,814	724	**50,840**
Jambi	17,268	926	458	6,210	260	**25,123**
Sumatera Selatan	37,635	1,585	1,579	10,919	628	**52,346**
Bengkulu	14,611	368	306	3,409	120	**18,814**
Lampung	21,253	2,600	1,070	13,017	292	**38,232**
Kep. Bangka Belitung	34,536	636	357	2,543	207	**38,279**
Kepulauan Riau	13,283	3,476	1,630	8,194	1,115	**27,699**
Total Sumatera	**225,370**	**21,109**	**14,518**	**102,372**	**5,344**	**368,712**

Province	Estimated Number of Transformers per Industry Type					Total Number of Transformers
	Pertambangan dan Penggalian	Industri Pengolahan	Pengadaan Listrik Gas/Uap Air Panas dan Udara Dingin	Perdagangan Besar dan Eceran	Penyediaan Akomodasi dan Penyediaan Makan Minum	
DKI Jakarta	25,681	16,199	8,558	73,889	13,432	**137,758**
Jawa Barat	79,699	51,303	9,271	84,346	6,672	**231,290**
Jawa Tengah	26,123	29,156	4,228	60,099	2,535	**122,141**
DI Yogyakarta	4,428	3,175	408	11,537	1,159	**20,706**
Jawa Timur	51,361	38,876	6,571	87,671	4,161	**188,641**
Banten	22,581	20,557	2,139	31,968	3,431	**80,676**
Total Java	**209,873**	**159,264**	**31,175**	**349,509**	**31,390**	**781,212**
Total Sumatera - Java (83.77%)	**435,243**	**180,374**	**45,693**	**451,881**	**36,734**	**1,149,924**
Outside Sumatera - Java (16.23%)	**84,297**	**34,934**	**8,850**	**87,519**	**7,114**	**222,714**
Total Indonesia	**519,539**	**215,308**	**54,543**	**539,400**	**43,848**	**1,372,638**

To estimate the number of transformers per province based on PCBs contamination level/category and manufacture year, the analysis was done based on the proportion of contamination category and proportion of manufacture year previously identified in descriptive analysis for the PCBs inventory sample database (sub-chapter 2.5.1 and 2.5.3). These proportions were then applied to the estimated population number of transformers per province as seen in the last column of Table 4-4 above.

The analysis and results can be found in the following Table 4-5 and Table 4-6.

Table 4-5 Estimated Population Number of Transformers per Province per PCBs Contamination Category

Province	Estimated Total Number of Transformers	Contamination Status			Number of Transformers per Contamination Category		
		PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm	PCBs < 50 ppm	50 ppm ≤ PCBs < 10,000 ppm	PCBs ≥ 10,000 ppm
Aceh	26,114	91.25%	8.53%	0.22%	23,828	2,228	58
Sumatera Utara	47,908	91.25%	8.53%	0.22%	43,714	4,088	106
Sumatera Barat	43,359	91.25%	8.53%	0.22%	39,563	3,699	96
Riau	50,840	91.25%	8.53%	0.22%	46,390	4,338	112
Jambi	25,123	91.25%	8.53%	0.22%	22,924	2,144	56
Sumatera Selatan	52,346	91.25%	8.53%	0.22%	47,764	4,466	116
Bengkulu	18,814	91.25%	8.53%	0.22%	17,167	1,605	42
Lampung	38,232	91.25%	8.53%	0.22%	34,885	3,262	85
Kep. Bangka Belitung	38,279	91.25%	8.53%	0.22%	34,928	3,266	85
Kepulauan Riau	27,699	91.25%	8.53%	0.22%	25,274	2,363	61
Total Sumatera	**368,712**	91.25%	8.53%	0.22%	**336,438**	**31,460**	**815**
DKI Jakarta	137,758	91.25%	8.53%	0.22%	125,700	11,754	305
Jawa Barat	231,290	91.25%	8.53%	0.22%	211,044	19,734	511
Jawa Tengah	122,141	91.25%	8.53%	0.22%	111,449	10,421	270
DI Yogyakarta	20,706	91.25%	8.53%	0.22%	18,894	1,767	46
Jawa Timur	188,641	91.25%	8.53%	0.22%	172,129	16,095	417
Banten	80,676	91.25%	8.53%	0.22%	73,614	6,884	178
Total Java	**781,212**	91.25%	8.53%	0.22%	**712,830**	**66,655**	**1,727**
Total Sumatera - Java (83.77%)	**1,149,924**	91.25%	8.53%	0.22%	**1,049,268**	**98,115**	**2,542**
Outside Sumatera - Java (16.23%)	**222,714**	91.25%	8.53%	0.22%	**203,219**	**19,003**	**492**
Total Indonesia	**1,372,638**	91.25%	8.53%	0.22%	**1,252,487**	**117,117**	**3,034**

Table 4-6 Estimated Population Number of Transformers per Province per Manufacture Year

Province	Total Number of Transformers	Manufacture Year (percentage)					Manufacture Year (Number of trasformers)				
		< 1983	1983 - 1992	1993 - 2002	> 2002	N/A	< 1983	1983 - 1992	1993 - 2002	> 2002	N/A
Aceh	**26,114**	15.56%	24.67%	34.00%	25.18%	0.60%	4,064	6,442	8,878	6,575	156
Sumatera Utara	**47,908**	15.56%	24.67%	34.00%	25.18%	0.60%	7,455	11,818	16,287	12,062	286
Sumatera Barat	**43,359**	15.56%	24.67%	34.00%	25.18%	0.60%	6,747	10,696	14,740	10,916	259
Riau	**50,840**	15.56%	24.67%	34.00%	25.18%	0.60%	7,911	12,541	17,284	12,800	303
Jambi	**25,123**	15.56%	24.67%	34.00%	25.18%	0.60%	3,909	6,197	8,541	6,325	150
Sumatera Selatan	**52,346**	15.56%	24.67%	34.00%	25.18%	0.60%	8,146	12,913	17,796	13,179	312
Bengkulu	**18,814**	15.56%	24.67%	34.00%	25.18%	0.60%	2,928	4,641	6,396	4,737	112
Lampung	**38,232**	15.56%	24.67%	34.00%	25.18%	0.60%	5,949	9,431	12,997	9,626	228
Kep. Bangka Belitung	**38,279**	15.56%	24.67%	34.00%	25.18%	0.60%	5,957	9,443	13,013	9,637	228
Kepulauan Riau	**27,699**	15.56%	24.67%	34.00%	25.18%	0.60%	4,310	6,833	9,417	6,974	165
Total Sumatera	**368,712**	15.56%	24.67%	34.00%	25.18%	0.60%	57,377	90,956	125,349	92,830	2,201
DKI Jakarta	**137,758**	15.56%	24.67%	34.00%	25.18%	0.60%	21,437	33,983	46,833	34,683	822
Jawa Barat	**231,290**	15.56%	24.67%	34.00%	25.18%	0.60%	35,992	57,056	78,630	58,232	1,380
Jawa Tengah	**122,141**	15.56%	24.67%	34.00%	25.18%	0.60%	19,007	30,130	41,523	30,751	729
DI Yogyakarta	**20,706**	15.56%	24.67%	34.00%	25.18%	0.60%	3,222	5,108	7,039	5,213	124
Jawa Timur	**188,641**	15.56%	24.67%	34.00%	25.18%	0.60%	29,355	46,535	64,131	47,494	1,126
Banten	**80,676**	15.56%	24.67%	34.00%	25.18%	0.60%	12,554	19,902	27,427	20,312	481
Total Java	**781,212**	15.56%	24.67%	34.00%	25.18%	0.60%	**121,568**	**192,713**	**265,584**	**196,684**	**4,662**
Total Sumatera - Java (83.77%)	**1,149,924**	15.56%	24.67%	34.00%	25.18%	0.60%	**178,945**	**283,668**	**390,934**	**289,515**	**6,863**
Outside Sumatera - Java (16.23%)	**222,714**	15.56%	24.67%	34.00%	25.18%	0.60%	**34,658**	**54,940**	**75,715**	**56,072**	**1,329**
Total Indonesia	**1,372,638**	15.56%	24.67%	34.00%	25.18%	0.60%	**213,602**	**338,608**	**466,648**	**345,587**	**8,192**

4.4.2 Estimating Population Number of Transformers per Province Based on Power Rating

Power rating was not one of the variables that was elaborated statistically in the descriptive analysis of PCBs inventory sample database (see Chapter 2). This was because the sample representativeness for all categories of power rating in sampled provinces varied greatly and most sampled provinces did not have samples for Medium and Large Power Transformers. To provide a detail breakdown per province for this variable may then produce misleading conclusions. Therefore, it was considered more valid to provide a proportion of sampled transformers' power ratings by using the whole sample data in the database (not per province).

From the current PCBs inventory sample database that included a total of 4,524 samples from the 1st and 2nd phase inventory, there were 4,466 Small Power Transformers (SPT), 52 Medium Power Transformers (MPT), and 6 Large Power Transformers. The sample proportion per power rating category can be found in the following Table 4-7.

Table 4-7 PCBs Inventory Database Sample Proportion per Power Rating Category

Power Rating Category	Number of Samples	Percentage
SPT (Small Power Transformers)	4,466	98.72%
MPT (Medium Power Transformers)	52	1.15%
LPT (Large Power Transformers)	6	0.13%
Total	**4,524**	**100%**

To estimate the population number of transformers per power rating category, the analysis was done by multiplying the estimated population number of transformers per province as seen in the last column of Table 4-4 with the proportion of samples per power rating category. The analysis result can be found in the following Table 4-8.

Table 4-8 Estimated Population Number of Transformers per Power Rating Category

Province	Estimated Total Number of Transformers	Power Rating			Number of Transformers per Power Rating		
		SPT (Small Power Transformer)	MPT (Medium Power Transformer)	LPT (Large Power Transformer)	SPT	MPT	LPT
Aceh	26,114	98.72%	1.15%	0.13%	25,779	300	35
Sumatera Utara	47,908	98.72%	1.15%	0.13%	47,294	551	64
Sumatera Barat	43,359	98.72%	1.15%	0.13%	42,803	498	58
Riau	50,840	98.72%	1.15%	0.13%	50,188	584	67
Jambi	25,123	98.72%	1.15%	0.13%	24,801	289	33
Sumatera Selatan	52,346	98.72%	1.15%	0.13%	51,675	602	69
Bengkulu	18,814	98.72%	1.15%	0.13%	18,572	216	25
Lampung	38,232	98.72%	1.15%	0.13%	37,742	439	51
Kep. Bangka Belitung	38,279	98.72%	1.15%	0.13%	37,788	440	51
Kepulauan Riau	27,699	98.72%	1.15%	0.13%	27,344	318	37
Total Sumatera	**368,712**	98.72%	1.15%	0.13%	**363,985**	**4,238**	**489**
DKI Jakarta	137,758	98.72%	1.15%	0.13%	135,992	1,583	183
Jawa Barat	231,290	98.72%	1.15%	0.13%	228,325	2,659	307
Jawa Tengah	122,141	98.72%	1.15%	0.13%	120,575	1,404	162
DI Yogyakarta	20,706	98.72%	1.15%	0.13%	20,441	238	27
Jawa Timur	188,641	98.72%	1.15%	0.13%	186,222	2,168	250
Banten	80,676	98.72%	1.15%	0.13%	79,642	927	107
Total Java	**781,212**	98.72%	1.15%	0.13%	**771,196**	**8,979**	**1,036**
Total Sumatera - Java (8377%)	**1,149,924**	98.72%	1.15%	0.13%	**1,135,182**	**13,218**	**1,525**
Outside Sumatera - Java (1623%)	**222,714**	98.72%	1.15%	0.13%	**219,859**	**2,560**	**295**
Total Indonesia	**1,372,638**	98.72%	1.15%	0.13%	**1,355,040**	**15,777**	**1,820**

4.5 *Estimating the Total Population Volume of PCBs Contaminated Transformer Oil in Indonesia*

After identifying the estimated population characteristics, analysis can be done to estimate the total population volume of contaminated transformer oil in Indonesia. In particular, this analysis required the estimated population number of transformers based on power rating because the volume of oil contained in transformers depended on their sizes which were related to their power rating.

In order to do this analysis, the first step would be to determine the proportion of contaminated transformers per power rating category. From the current PCBs inventory sample database that included a total of 4,524 samples from the 1st and 2nd phase inventory, there were 4,466 SPT with 394 of them were contaminated by PCBs (PCBs ≥ 50ppm), 52 MPT with one (1) contaminated by PCBs (PCBs ≥ 50ppm), and 6 LPT with one (1) contaminated by PCBs (PCBs ≥ 50ppm).

Table 4-9 Proportion of Contaminated Samples per Power Rating Category

Power Rating Category	Number of Samples	Number of Contaminated Samples (PCBs ≥ 50ppm)	Percentage of Contaminated Samples
SPT (Small Power Transformers)	4,466	394	8.82%
MPT (Medium Power Transformers)	52	1	1.92%
LPT (Large Power Transformers)	6	1	16.67%
Total	**4,524**	**396**	**8.75%**

Here the analysis did not break down the PCBs contamination category and only stated "contaminated samples (PCBs ≥ 50ppm)" because there were only one (1) sample contaminated by PCBs for MPT and LPT, and the contaminated samples in both MPT and LPT category fell under the 50ppm ≤ PCBs < 10,000ppm in contamination category. All samples with PCBs ≥ 10,000ppm were in the SPT group. For this reason, detailing the PCBs contamination category per power rating may be misleading, particularly in assessing MPT and LPT, due to the lack of variance in contaminated samples.

The second step was to determine the average oil volume per transformer in each power rating category. This was done by using the PCBs inventory database, particularly by totalling all of oil volume data from all samples in each power rating category and then divided the result with the number of samples of each respective category. The total volume of oil from samples inventory database (divided for phase 1 and 2) can be seen in the following Table 4-10. The result of estimating average oil volume per transformer for each power rating category can be seen in the following Table 4-11.

Table 4-10 Total Volume of Oil from Samples Inventory Database

Power Rating Category	1st Phase PCBs Inventory		2nd Phase PCBs Inventory		Total Volume of Oil per Category
	Number of Samples	Total Volume of Oil (Kg)	Number of Samples	Total Volume of Oil (Kg)	
SPT (Small Power Transformers)	2,973	4,236,865	1,493	3,088,591	7,325,456
MPT (Medium Power Transformers)	41	883,645	11	383,220	1,266,865
LPT (Large Power Transformers)	1	92,000	5	636,800	728,800
Total	**3,015**	**5,212,510**	**1,509**	**4,108,611**	**9,321,121**

Table 4-11 Estimated Average Oil Volume per Transformer per Power Rating Category

Power Rating Category	Oil Volume (Data Sample)		Estimated Average Oil Volume per Transformer (Kg)
	Total (Kg)	Number of Samples	
SPT (Small Power Transformers)	7,325,456	4,466	**1,640.27**
MPT (Medium Power Transformers)	1,266,865	52	**24,362.79**
LPT (Large Power Transformers)	728,800	6	**121,466.67**
Total	**9,321,121**	**4,524**	**2,060.37**

The third step was to estimate the number of contaminated transformers per power rating category per province. This was done by multiplying the proportion of PCBs contaminated transformers per power rating category (from Table 4-9) with the number of transformers per power rating per provinces (from Table 4-8). After this step, we can estimate the total oil volume from only the contaminated transformers per province. This was done by multiplying the number of contaminated transformers per power rating category per province with the average oil volume per transformer per power rating category (from Table 4-11).

To make it more detail, the analysis was continued with estimating the PCBs contaminated oil volume per contamination category. As explained above in Table-39 description, detailing the PCBs contamination category directly from samples per power rating may be misleading (as MPT and LPT each only had one (1) sample contaminated by PCBs). Therefore, proportion of "50ppm ≤ PCBs < 10,000ppm" and "PCBs ≥ 10,000ppm" was identified by using the total number of contaminated samples (concentration ≥ 50ppm).

From analysis done earlier in Chapter 2, we had identified that from the total of 396 contaminated samples, there were 10 samples with PCBs ≥ 10,000ppm and the rest of 386 samples were contaminated with 50ppm ≤ PCBs < 10,000ppm. The proportion per contamination category from the contaminated samples group was identified in the following Table 4-12.

Table 4-12 Proportion per Contamination Category from Contaminated Samples Group

Contamination Category	Number of Samples	Percentage
50ppm ≤ PCBs < 10000ppm	386	97.47%
PCBs ≥ 10000ppm	10	2.53%
Total	**396**	**8.75%**

The analysis to estimate the total population volume of PCBs contaminated transformer oil in Indonesia as elaborated above can be found in the following Table 4-13.

Table 4-13 Estimated Total Population Volume of PCBs Contaminated Transformer Oil in Indonesia

Province	Estimated Total Number of Transformers	Number of Transformers			Estimated Number of Contaminated Transformers (PCBs ≥ 50ppm)			Estimated Contaminated Oil Volume (Kg)				Estimated contaminated oil volume (kg) per contamination status	
		SPT	MPT	LPT	SPT (8.82% contaminated)	MPT (1.92% contaminated	LPT (16.67% contaminated)	SPT (avg. 1640.27 Kg)	MPT (Avg. 24362.79)	LPT (Avg. 121466.67 Kg)	Total	50 ppm ≤ PCBs < 10000 ppm (97.47%)	PCBs ≥ 10000 ppm (253%)
Aceh	26,114	25,779	300	35	2,274	6	6	3,729,540.08	140,405.53	701,288.32	4,571,233.94	4,455,581.72	115,652.22
Sumatera Utara	47,908	47,294	551	64	4,171	11	11	6,842,060.53	257,582.21	1,286,554.66	8,386,197.40	8,174,026.60	212,170.79
Sumatera Barat	43,359	42,803	498	58	3,775	10	10	6,192,368.64	233,123.34	1,164,389.10	7,589,881.08	7,397,857.09	192,023.99
Riau	50,840	50,188	584	67	4,427	11	11	7,260,784.40	273,345.85	1,365,289.88	8,899,420.13	8,674,264.81	225,155.33
Jambi	25,123	24,801	289	33	2,187	6	6	3,587,942.69	135,074.84	674,662.90	4,397,680.42	4,286,419.11	111,261.31
Sumatera Selatan	52,346	51,675	602	69	4,558	12	12	7,475,952.56	281,446.26	1,405,749.27	9,163,148.10	8,931,320.45	231,827.65
Bengkulu	18,814	18,572	216	25	1,638	4	4	2,686,909.94	101,153.77	505,236.18	3,293,299.88	3,209,979.40	83,320.49
Lampung	38,232	37,742	439	51	3,329	8	8	5,460,157.07	205,557.86	1,026,706.86	6,692,421.79	6,523,103.52	169,318.27
Bangka Belitung	38,279	37,788	440	51	3,333	8	8	5,466,855.19	205,810.02	1,027,966.35	6,700,631.56	6,531,105.58	169,525.98
Kep. Riau	27,699	27,344	318	37	2,412	6	6	3,955,847.97	148,925.32	743,842.39	4,848,615.68	4,725,945.70	122,669.98
Sumatera	**368,712**	363,985	4,238	489	32,104	81	82	52,658,419.07	1,982,425.00	9,901,685.92	**64,542,529.99**	**62,909,603.98**	**1,632,926.01**
DKI Jakarta	137,758	135,992	1,583	183	11,994	30	30	19,674,186.50	740,671.67	3,699,458.11	24,114,316.27	23,504,224.07	610,092.20
Jawa Barat	231,290	228,325	2,659	307	20,138	51	51	33,032,154.84	1,243,557.45	6,211,238.93	40,486,951.21	39,462,631.35	1,024,319.87
Jawa Tengah	122,141	120,575	1,404	162	10,635	27	27	17,443,746.98	656,702.59	3,280,054.87	21,380,504.43	20,839,577.67	540,926.76
Yogyakarta	20,706	20,441	238	27	1,803	5	5	2,957,209.77	111,329.71	556,062.31	3,624,601.79	3,532,899.37	91,702.43
Jawa Timur	188,641	186,222	2,168	250	16,425	42	42	26,941,127.74	1,014,249.31	5,065,905.70	33,021,282.75	32,185,844.29	835,438.45
Banten	80,676	79,642	927	107	7,024	18	18	11,521,932.38	433,764.76	2,166,539.70	14,122,236.84	13,764,944.25	357,292.59
Java	**781,212**	771,196	8,979	1,036	68,020	172	173	111,570,358.19	4,200,275.49	20,979,259.62	**136,749,893.30**	**133,290,121.00**	**3,459,772.30**
Sumatera – Java	**1,149,924**	1,135,182	13,218	1,525	100,123	254	254	164,228,777.27	6,182,700.48	30,880,945.54	**201,292,423.28**	**196,199,724.97**	**5,092,698.31**
Outside Sumatera - Java	**222,714**	219,859	2,560	295	19,392	49	49	31,807,344.37	1,197,447.16	5,980,930.29	**38,985,721.83**	**37,999,383.07**	**986,338.76**
Indonesia	**1,372,638**	1,355,040	15,777	1,820	119,515	303	303	196,036,121.64	7380147.64	36,861,875.83	**240,278,145.11**	**234,199,108.04**	**6,079,037.07**

4.6 *Estimating the Total Population Shell Weight (Equipment Weight) of Contaminated Transformers in Indonesia*

Estimating the total population shell weight (equipment weight) of contaminated transformers used similar steps as estimating the oil volume in sub-chapter 3.4. The steps were as follow:

1. Determined the proportion of contaminated transformers per power rating category (from Table 4-9).
2. Determined the average equipment weight in each power rating category. This was done by using the PCBs inventory database, particularly by totalling all of equipment weight data from all samples in each power rating category and then divided the result with the number of samples of each respective category. The total weight of equipment from samples inventory database (divided for phase 1 and 2) can be seen in the following Table 4-14. The result can be seen in the following Table 4-15.

Table 4-14 Total Weight of Equipment from Samples Inventory Database

Power Rating Category	1st Phase PCBs Inventory		2nd Phase PCBs Inventory		Total Weight of Equipment per Category
	Number of Samples	Total Weight of Equipment (Kg)	Number of Samples	Total Weight of Equipment (Kg)	
SPT (Small Power Transformers)	2,973	11,752,071	1,493	9,049,196	20,801,267
MPT (Medium Power Transformers)	41	2,451,015	11	969,960	3,420,975
LPT (Large Power Transformers)	1	368,000	5	967,300	1,335,300
Total	**3,015**	**14,571,086**	**1,509**	**10,986,456**	**25,557,542**

Table 4-15 Estimated Average Equipment Weight per Transformer per Power Rating Category

Power Rating Category	Equipment Weight (Data Sample)		Estimated Average Equipment Weight per Transformer (Kg)
	Total (Kg)	Number of Samples	
SPT (Small Power Transformers)	20,801,267	4,466	**4,657.70**
MPT (Medium Power Transformers)	3,420,975	52	**65,787.98**
LPT (Large Power Transformers)	1,335,300	6	**222,550.00**
Total	**25,557,542**	**4,524**	**5,649**

3. Estimated the number of contaminated transformers per power rating category per province, continued by estimating the total equipment weight from only the contaminated transformers per province.
4. Estimated the total population of PCBs contaminated equipment weight per contamination category.
5. The analysis to estimate the total equipment weight of PCBs contaminated transformers in Indonesia as elaborated above can be found in the following Table 4-16.

Table 4-16 Estimated Total Population Equipment Weight of PCBs Contaminated Transformers in Indonesia

Province	Estimated Total Number of Transformers	Number of Transformers			Estimated Number of Contaminated Transformers (PCBs ≥ 50ppm)			Estimated Equipment Weight of Contaminated Transformers (Kg)				Estimated Equipment Weight of Contaminated Transformers (kg) per contamination status	
		SPT	MPT	LPT	SPT (8.82% contaminated)	MPT (1.92% contaminated	LPT (16.67% contaminated)	SPT (avg. 4657.7 Kg)	MPT (Avg. 65787.98)	LPT (Avg. 222550 Kg)	Total	50 ppm ≤ PCBs < 10000 ppm (97.47%)	PCBs ≥ 10000 ppm (253%)
Aceh	26,114	25,779	300	35	2,274	6	6	10,590,377.70	379,143.62	1,284,893.35	12,254,414.67	11,944,377.98	310,036.69
Sumatera Utara	47,908	47,294	551	64	4,171	11	11	19,428,670.48	695,561.27	2,357,212.39	22,481,444.13	21,912,663.60	568,780.54
Sumatera Barat	43,359	42,803	498	58	3,775	10	10	17,583,809.63	629,513.84	2,133,381.90	20,346,705.37	19,831,933.73	514,771.65
Riau	50,840	50,188	584	67	4,427	11	11	20,617,676.06	738,128.58	2,501,470.26	23,857,274.90	23,253,685.84	603,589.05
Jambi	25,123	24,801	289	33	2,187	6	6	10,188,298.67	364,748.89	1,236,110.51	11,789,158.08	11,490,892.38	298,265.70
Sumatera Selatan	52,346	51,675	602	69	4,558	12	12	21,228,666.17	760,002.49	2,575,599.55	24,564,268.21	23,942,792.22	621,475.99
Bengkulu	18,814	18,572	216	25	1,638	4	4	7,629,731.95	273,150.24	925,688.59	8,828,570.78	8,605,207.94	223,362.84
Lampung	38,232	37,742	439	51	3,329	8	8	15,504,626.42	555,077.49	1,881,121.90	17,940,825.80	17,486,922.91	453,902.89
Bangka Belitung	38,279	37,788	440	51	3,333	8	8	15,523,646.35	555,758.42	1,883,429.52	17,962,834.29	17,508,374.58	454,459.71
Kep. Riau	27,699	27,344	318	37	2,412	6	6	11,233,000.12	402,150.00	1,362,860.47	12,998,010.59	12,669,160.92	328,849.67
Sumatera	**368,712**	363,985	4,238	489	32,104	81	82	149,528,503.55	5,353,234.83	18,141,768.45	**173,023,506.83**	**168,646,012.10**	**4,377,494.72**
DKI Jakarta	137,758	135,992	1,583	183	11,994	30	30	55,866,691.73	2,000,070.31	6,778,109.60	64,644,871.64	63,009,356.39	1,635,515.25
Jawa Barat	231,290	228,325	2,659	307	20,138	51	51	93,797,891.55	3,358,036.28	11,380,168.93	108,536,096.76	105,790,133.51	2,745,963.25
Jawa Tengah	122,141	120,575	1,404	162	10,635	27	27	49,533,150.21	1,773,324.67	6,009,683.24	57,316,158.12	55,866,059.32	1,450,098.80
Yogyakarta	20,706	20,441	238	27	1,803	5	5	8,397,273.58	300,628.82	1,018,811.73	9,716,714.12	9,470,881.26	245,832.87
Jawa Timur	188,641	186,222	2,168	250	16,425	42	42	76,501,850.72	2,738,824.79	9,281,701.00	88,522,376.51	86,282,760.38	2,239,616.13
Banten	80,676	79,642	927	107	7,024	18	18	32,717,604.07	1,171,315.26	3,969,512.05	37,858,431.38	36,900,613.06	957,818.31
Java	**781,212**	771,196	8,979	1,036	68,020	172	173	316,814,461.86	11,342,200.12	38,437,986.55	**366,594,648.53**	**357,319,803.92**	**9,274,844.61**
Sumatera – Java	**1,149,924**	1,135,182	13,218	1,525	100,123	254	254	466,342,965.41	16,695,434.95	56,579,755.00	**539,618,155.36**	**525,965,816.03**	**13,652,339.33**
Outside Sumatera - Java	**222,714**	219,859	2,560	295	19,392	49	49	90,319,927.75	3,233,522.51	10,958,199.79	**104,511,650.05**	**101,867,505.30**	**2,644,144.75**
Indonesia	**1,372,638**	1,355,040	15,777	1,820	119,515	303	303	556,662,893.16	19,928,957.46	67,537,954.78	**644,129,805.41**	**627,833,321.33**	**16,296,484.08**

5 Conclusion and Recommendation

From the analysis conducted, several conclusions were taken as follow:

- From factor analysis, it can be concluded that “manufacture year” of transformers was a significant influential factor in PCBs contamination. Power rating, voltage and type of transformers were not a significant factor in PCBs contamination.

  However, although the contamination data per manufacture year validated the factor analysis result, and showed that the older transformers were more likely to be contaminated by PCBs, it also showed that the newer transformers still had samples contaminated by PCBs. Ideally, newer transformers should not be contaminated by PCBs, as they were manufactured after the utilisation of PCBs was prohibited in 1983. This was a strong indication that cross-contamination during purification or reclamation process is another source of PCBs contamination in transformers in Indonesia.

- From t-test analysis, it was shown that Askarel-A conversion approach (using Dexsil analyzer) and IEC-61619 (using GC-ECD instrument) produced similar results in analyzing PCBs contamination. Therefore, it can be concluded that Dexsil analyzer with Askarel-A conversion approach is reliable to be used for screen-testing PCBs contamination in transformers.

- Based on the extrapolation analysis, the estimated total number of transformers in Indonesia, not including transformers of PT PLN, was (at minimum) **1,372,638** transformers. The general characteristics of this population were as follow:

  - The proportion of PCBs contaminated samples from the combined database was 8.75%. Therefore, from the estimated number of 1,372,638 transformers population in Indonesia, there were **120,106** transformers (8.75%) contaminated by PCBs.

  - From the estimated 120,106 contaminated transformers, it was estimated that 117,117 transformers had 50ppm ≤ PCBs < 10000ppm of PCBs contamination level and 3,034 transformers had PCBs ≥ 10000ppm of PCBs contamination level.

  - From the estimated 120,106 contaminated transformers, it was estimated that the amount of contaminated transformers oil that needs to be processed were 234,199,108.04 kg of oil with 50ppm ≤ PCBs < 10000ppm of PCBs contamination level and 6,079,037.07 kg of oil with PCBs ≥ 10000ppm of PCBs contamination level.

  - From the estimated 120,106 contaminated transformers, it was estimated that the amount of contaminated transformers shell weight that needs to be processed were 627,833,321.33 kg in total for transformers with 50ppm ≤ PCBs < 10000ppm of PCBs contamination level and 16,296,484.08 kg in total for transformers with PCBs ≥ 10000ppm of PCBs contamination level.

Based on the analysis conducted, the recommendations from this research are as follow:

- To complete the PCBs inventory database and to provide better national-scale overview of PCBs contamination in transformers in Indonesia, census or survey is needed for transformers outside Java and Sumatera region.
- To complete the PCBs inventory database, data from PLN needs to be included for next research or analysis. The data from PLN should use the same format or data structure to allow merging with the existing PCBs inventory database.
- To improve the efficiency of testing and transporting of PCBs contaminated equipment and samples, more PCBs disposal facilities and laboratories should be built and placed in provinces with the highest estimated numbers of PCBs contaminated transformers.
- To lower the potential risk of PCBs cross-contamination in transformers purification process, it is recommended to develop some type of certification or standards for PCBs-free transformers purification equipment.
- The analysis results showed that maintenance plays a key role in PCBs contamination to transformer oil. Therefore, it is recommended that Indonesia have a policy or regulation to ensure better recordings all of the action taken during the maintenance process, especially if there were oil replacement or retro-filling during the maintenance.

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