

**Cost-Benefit Analysis**

**for the Disposal of the PCB-Containing Transformers**

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**United Nations Development Programme (UNDP)**

**Project: Comprehensive Environmentally Sound Management of PCBs in Montenegro**

**Cost-Benefit Analysis for the Disposal of the PCB Containing Transformers**

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**Abbreviations**

|  |  |
| --- | --- |
| CEDIS | Electro Distributive System of Montenegro |
| CETI | Center for Eco-Toxicological Research |
| ESM | Environmentally Sound Management |
| GEF | Global Environment Facility |
| IPH | Institute of Public Health |
| MSDT | Ministry of Sustainable Development and Tourism |
| NEPA | Nature and Environmental Protection Agency |
| NIP | National Implementation Plan |
| NPPM | National Plan on PCB Management |
| OGM | Official Gazette of Montenegro |
| PCBs | Polychlorinated biphenyls |
| PCTs | Polychlorinated terphenyls |
| PCDDs | Polychlorinated dibenzodioxins |
| PCDFs | Polychlorinated dibenzofurans |
| POPs | Persistent Organic Pollutants |
| PPE | Personnel Protective Equipment |
| ppm | Parts per million |
| UNDP | United Nations Development Programme |

**Executive Summary**

Montenegro has been a state party to the Stockholm Convention on Persistent Organic Pollutants (POPs) since March 2011 and in response to Article 7 the country developed its National Implementation Plan (NIP) in November 2013. Montenegro updated it in July 2019. The purpose of the National Implementation Plan for the Stockholm Convention (NIP) is to contribute to the implementation of the obligations arising from the Convention, to raise awareness of POPs and measures for their control, to present measures undertaken and establish a strategy and action plans for further steps related to management of POPs.

The country committed itself in its NIP to phase out the use of PCBs in equipment until 2020 and ensure elimination of PCBs until 2023. Preparation of this Plan is of crucial importance to ensure the environmentally sound management (ESM) of PCBs thus reaching the above-mentioned goals.

The cost-benefit analysis makes a comparison of different scenarios for final disposal and destruction of PCB-containing transformers, which will help to evaluate whether to export the PCB containing equipment/waste for disposal abroad, to purchase and install treatment unit in an operating entity or to lease, depending on the PCB portfolio including PCB quantity and concentrations.

Three scenarios for the disposal of the PCB-contaminated transformers have been envisaged, by taking into consideration several factors, like: the PCB concentration; the life-cycle management, i.e. re-use of the transformer after the treatment; possibilities for export of the PCB-containing transformers to the available treatment facilities in the region; possibilities for leasing of the unit for the treatment in Montenegro, etc. The following scenarios are considered: **I.** Export and final disposal of the PCB contaminated transformers is considered in two variants: **I.1** Export and incineration of complete PCB contaminated transformer; and **I.2** Export and treatment of complete PCB contaminated equipment; **II.** Retrofilling followed by export and incineration of PCB contaminated oil and cellulosic material from disposed-off transformers, while the equipment will be returned to operation or disassembled; and **III.** The dehalogenation scenario is considered in three variants: **III.1** Purchasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP) in the country; **III.2** Leasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP); **III.**3 Export of the PCB-containing transformers for treatment abroad and returning the treated transformers back for re-use.

Based on the analysis, it can be concluded that the scenario **III.3** Export of the PCB-containing transformers for treatment abroad, i.e. in the established treatment facilities in the Balkan region and returning the treated transformers back for re-use represents the most viable disposal solution for the PCB-containing transformers. On the other hand, the high investment costs of the disposal scenario III.1 cannot be justified with the expected level of benefit. The scenario II. Retrofilling also represent a viable disposal solution for the low PCB-containing transformers, but the identified disadvantages prevents this option to be favourable one.

Moreover, separate analyses on the cost estimates have been made for the specially designed transformers from KAP with high PCB concentrations. Two disposal scenarios have been taken into consideration: **A.** Export for incineration of the entire transformer and **B.** Retrofilling in order to define the option which is economically more acceptable. Based on the analysis, the disposal scenario **A.** Export for incineration of the entire transformer has been found economically far more acceptable than the retrofilling option.

# Introduction

## Project Background and Rationale

The main objective of the project “Comprehensive Environmentally Sound Management of PCBs in Montenegro” is to assist the Republic of Montenegro to comply with the PCB-related obligations under the Stockholm Convention and reduce the releases of PCBs into the environment through the implementation of the following components: i) Capacity strengthening on PCB management; ii) PCB Inventory, planning and establishment of public-private partnership; iii) Environmentally Sound Management (ESM) of PCBs, and, iv) Monitoring, Learning, Adaptive Feedback and Evaluation.

The preparation of the Cost-Benefit Analysis falls within Component 3 of the Project “Environmentally sound management (ESM) of PCBs”, especially Output 3.2 aimed on “Identification, assessment and procurement of environmentally sound PCBs disposal technologies or services”. One of the activities related to Component 3 is the destruction/treatment of 700 tons of PCB containing equipment and waste in environmentally sound manner, ensuring that the activities of PCB disposal will be carried out in compliance with BAT/BEP and at the best cost/effectiveness ratio.

## Goals and Objectives of the Cost-Benefit Analysis

The Cost-Benefit Analysis is the main tool that supports the decisions making process for financing the disposal strategy for the PCB-containing transformers. The key objective of the cost-benefit analysis is to quantify the expected costs for several disposal scenarios, demonstrating the most feasible option for the disposal of the PCB-containing transformers.

The preparation of the cost-benefit analysis was based on rationalization of the inventory results and reasonable estimation on PCB-containing equipment and waste for the whole country, by taking into consideration the country needs, nature and quantity of waste streams, economic and market conditions.

## Cost-Benefit Analysis Format

The findings of the analysis are presented in Sections 2 through 5 of this report. Supporting information is provided in the Annexes, wherein of particular importance are documents prepared within the project (namely “Inventory of PCB-containing equipment and waste” and “Market research on potential bidders for PCB containing waste export tender“) serving as background research aimed at providing specific input data for the analysis.

Section 2 of the report provides an overview of the inventory of the PCB-containing transformers. Overview of the available PCB destruction/treatment technologies is presented in Section 3. The disposal scenarios for the PCB-containing transformers are presented in Section 4, then the detailed cost-benefit analysis is presented in Section 5 and Section 6, while the conclusions from the analysis are provided in Section 7.

# Inventory of PCB-containing Transformers

PCBs have never been produced in the territory of Montenegro, but there has been production and overhaul of equipment containing PCBs in the factory “19 decembar” in Podgorica (transformers and capacitors), which resulted in import of fluids containing PCBs.

PCB-containing equipment, capacitors and transformers, were mostly procured/imported from the Slovenian plant ISKRA – Semič, Serbian plant MINEL - Ripanj and AVALA – Belgrade, from former USSR and former GDR and other European and world manufacturers (ASEA - Sweden).

The data needed for the calculation of the identified, estimated and disposed quantities of PCB containing equipment and waste were obtained from several PCB identification and disposal processes, namely from the data provided in the National Implementation Plan (NIP) for the Stockholm Convention on POPs; then during the preparatory and the implementation phase of the project “Comprehensive Environmentally Sound Management of PCBs in Montenegro”, implemented by UNDP; and from the disposal attempts organized by the Government of Montenegro and the private sector.

The document “Inventory of PCB-containing equipment and waste” prepared within the project provides data on identified and estimated quantities of PCB-containing transformers, as well as the disposed ones. Having in mind the common factors like: exploitation practices of these transformers, technical characteristics, usage, servicing, manipulation and topping-up, as well as the level of PCB contamination which requires different disposal technologies, the PCB-containing transformers have been summarized in two groups: from the low-voltage network which have low PCB contamination and from the industrial sector which have higher PCB contamination.

The PCB-contaminated transformers from the low-voltage network, owned or maintained by CEDIS, are summarized in the Table 1 (including 7 transformers that are expected to be identified from the ones that remain to be subject of the inventory process); then from the industrial sector in the Table 2, while the categorization of the PCB-containing transformers from the low-voltage network and the industrial sector in accordance with different ranges of PCB contamination in the Annex 1.

Table 1: PCB-containing transformers from the low-voltage network

|  |  |  |  |
| --- | --- | --- | --- |
| **Description** | **Type of transformers** | | **Total** |
| **stationary** | **pole mounted** |
| Number of pieces | 46 | 22 | **68** |
| Weight of oil (kg) | 20,742 | 2,808 | **23,550** |
| Total weight (kg) | 90,102 | 12,750 | **102,852** |

Note that there are 6 transformers declared by the nameplate as PCB containing ones and these transformers are not presented in the table above.

Table 2: PCB-containing transformers from industrial sector remaining for disposal

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **Status of operation** | | | | | | **Total** | | |
| **Phased-out** | | | **In-use/Reserve** | | |
| **Pieces** | **Weight (kg)** | | **Pieces** | **Weight (kg)** | | **Pieces** | **Weight (kg)** | |
| **Oil** | **Total** | **Oil** | **Total** | **Oil** | **Total** |
| UNIPROM KAP | 35 | 37,042 | 128,895 | 30 | 27,679 | 104,675 | 65 | 64,721 | 233,570 |
| POLITROPUS | 16 | 2,810 | 47,271 | 1 | 1,280 | 4,200 | 17 | 4,090 | 51,471 |
| **Total:** | **51** | **39,852** | **176,166** | **31** | **28,959** | **108,875** | **82** | **68,811** | **285,041** |

It can be revealed that from the low-voltage network 58 transformers out of 68 PCB-contaminated ones or 85.3% have PCB concentration between 50-500 ppm (with the weight of oil of 19,279 kg and the total weight of 84,153 kg); then 6 transformers or 8.8% have PCB concentration between 500-2,000 ppm (with the weight of oil of 3,043 kg and the total weight of 13,804 kg) and 4 transformers or 5.9% have PCB concentration above 2,000 ppm (with the weight of oil of 1,228 kg and the total weight of 4,895 kg).

From the industrial sector 7 transformers out of 82 PCB-containing ones or 8.5% have PCB concentration between 50-500 ppm (with the weight of oil of 6,298 kg and the total weight of 24,330 kg); then 8 transformers or 9.8% have PCB concentration between 500-2,000 ppm (with the weight of oil of 7,765 kg and the total weight of 30,190 kg) and 67 transformers or 81.7% have PCB concentration above 2,000 ppm (with the weight of oil of 54,748 kg and the total weight of 230,521 kg). It can be observed that majority of the transformers with lower PCB concentrations, i.e. up to 2,000- 20,000 ppm were initially filled with “pure” PCB oil (askarel, pyralene) and then retrofilled using in most of the cases silicone oil as replacement one.

# Available PCB Destruction/Treatment Technologies

The subject for the analysis were those technologies that are able to destroy/treat the transformers containing PCBs at low and high levels. The technical guideline on disposal of the PCBs prepared within the project “Comprehensive Environmentally Sound Management of PCBs in Montenegro” provides detailed description on the disposal technologies applicable to different PCB waste streams (solids, oil, soil, sludge, then different types of equipment, like transformers, capacitors, etc.).

Methods of disposal of PCBs must meet the DE of 99,99% and DRE of 99,9999% and must be consistent with best available techniques (BAT) and best environmental practices (BEP) enjoined by the Stockholm convention. Environmentally Sound Technologies maximize environmental protection, minimize environmentally damaging emissions, use resources in a sustainable manner, minimize waste generation, maximize waste/by-product recycling, and responsibly handle what residual wastes that are generated.

Recovery of suitably decontaminated articles or liquids for scrap metal or for re-use, such as: transformers, hydraulic equipment, heat exchanger equipment, and mineral oils, should be given first priority. Incineration should be given second priority. Landfilling of PCBs is usually not an alternative, regardless the fact that this is not strictly banned by the law.

Based on the types and concentration of the PCBs intended for disposal, there could be three different types of technologies that could be used: i) technologies that destroy the contaminant (e.g. incineration, dechlorination or biodegradation), ii) technologies that only separate and/or concentrate the pollutant (e.g. solvent extractions, thermal desorption) and those technologies that only immobilize contaminants (e.g. landfill systems, stabilization and vitrification).

In this section focus is placed and short summary is provided only to those technologies applicable, proven and widely used to destroy/treat the PCB containing transformers and separate/concentrate of the PCBs at different contamination levels:

1. **High Temperature Incineration**

High temperature incineration (HTI) is a well-established, proven, and most widely used technology for the disposal of high concentrated PCB oil and PCB containing carcasses and the wastes. Transformers are normally shredded before incineration. In non-slagging kilns, the shredded transformer parts are subjected to temperatures in the range of 800-900 ºC and the incinerated metal can be either recycled or landfilled. Slagging incinerators operate at higher temperatures and the metal components of the transformer melt and form a slag; the metal cannot be recovered for recycling, but is usually landfilled.

Some incineration companies have a first treatment step for electrical equipment which involves solvent cleaning of the equipment (transformers and/or capacitors), with recovery of metals for recycling, while some other incinerators have established cooperation with the PCB equipment decontamination facilities. Some difficult-to-decontaminate components such as organic materials are then incinerated, together with the distilled solvents. Such companies are included in this report.

Incineration involves the degradation of waste by thermal energy in the presence of oxygen. The main products of high temperature incineration are carbon dioxide and water, and an inorganic ash. The chloride present is converted to hydrogen chloride gas, which is removed, together with other compounds, which can be formed as by-products of combustion, using air pollution control equipment. Appropriate designs of incineration plant is capable of dealing with concentrated PCBs liquids, solid PCBs contaminated items and articles such as capacitors, pieces of transformers, and drums, and low contamination wastes such as packaging and soil contaminated with traces of PCBs. In all cases incinerators intended to handle PCBs must be capable of high destruction efficiency such as 99.9999%. Such destruction efficiency could be obtained through a sustained operation at temperatures of around 1200˚C which include post-combustion chamber, provide a gas-phase residence time of at least two seconds, efficient acid gas-scrubbing plant, and sophisticated control equipment.

1. **Dehalogenation processes**

Chemical dechlorination is based on reactions with either an organically bound alkali metal (sodium naphthalide or sodium/potassium polyethylene glycol), or an alkali metal oxide or hydroxide. Chemical processes are well developed and used commercially to treat liquid PCBs, and PCB contaminated oil. The chlorine content is converted to inorganic salts, which can be removed from the organic fraction, by filtration or centrifugation.

* Dehalogenation processes using sodium, lithium and derivatives

These processes are typically applied in a batch and use reagents based on metallic sodium, sodium hydride, lithium hydride and additives, for the dehalogenation of PCBs in the oil. This type of process is typically run under pressure and medium to high temperature (150 °C – 300 °C). This temperature is higher than the flash point of the oil (typically 130 °C – 150 °C) and therefore introduces subsequent safety risks.

Warning: Proper measures should be taken to minimize the risk of fire or explosion, especially in the presence of wet oil. In their safety data sheets Sodium, Lithium and Derivatives are classified as flammable products and this is not in accordance with Art. 6.2 of Council Directive 96/59/EC: “shall be kept away from any flammable products”.

* Dehalogenation processes using polyethylene glycol and potassium hydroxide (KPEG)

This process, developed to overcome the problems associated with the use of metallic sodium, uses a liquid reagent based on polyethylene glycol (PEG) and an alkaline metal hydroxide such as potassium hydroxide (KOH). This type of process, which is run at temperatures of typically of 130– 150 °C, has a limited efficiency on some types of contaminants (e.g. Aroclor 1242).

* Dehalogenation in continuous mode by closed circuit process

This process uses a solid reagent consisting of a high molecular weight glycol mixture, a mixture of bases and a radical promoter or other catalyst for chemical conversion of organic chlorine to inert salts, on a high surface area particulate support. This process normally runs typically at 80 °C – 100 °C and has the capability to decontaminate equipment on-site, through continuous circulation of the oil in a closed system (without draining the oil or using auxiliary tanks), using the solvent capability of the oil for continuous extraction of PCB from solid materials inside the equipment.

1. **PCB extraction and concentration processes**

Liquid PCBs can be removed from transformers to allow safe disposal or recycle of the solid components. Metallic and non-metallic components contaminated with PCBs cannot be recycled until after the contamination has been removed. The decontaminated equipment may then be recycled in conventional plants such as metal foundries.

The complete decontamination of a transformer presents problems, due to the structure of this equipment. Although metal surfaces such as casings can be easily de-contaminated, the main problems arise with the porous materials in transformers, like varnish coating the copper wires, wooden struts and insulating paper. If not decontaminated to acceptable PCB levels allowing landfilling (which vary from country to country) these parts must be incinerated.

* Solvent decontamination: There are various solvent decontamination methods, some of which rely heavily on unsophisticated or manual methods such as dipping and flushing of disassembled parts, and others which involve more sophisticated facilities such as autoclaves using solvent under vacuum. The metal components are given a serious of vigorous solvent flushes. The solvent is regenerated through distillation and together with the combustible components are shipped to hazardous waste incinerator for disposal, while the decontaminated metal components are shipped to metal recycling facilities for smelting.
* Thermal desorption: Thermal desorption is the application of heat to volatilize and remove mainly organic contaminants from solids such as equipment components. The volatilized contaminants can be condensed and collected as an oily residue of substantially less volume than the original sediment mass. Thermal desorption processes for equipment solids are designed like a large oven and the solids are placed inside and “baked”. The thermal desorption can be applied by high vacuum desorption where all liquid PCB will be evaporated with a combination of vacuum and temperature under inert atmosphere using nitrogen.

1. **Retrofilling**

Retrofilling of a transformer means emptying the equipment of its dielectric fluid, and replacing this with new non-PCB oil. This operation can be quite long, since the inside of a transformer is complex. A more serious problem is related to the fact that the transformer usually contains wooden and paper components. These materials are porous and retain the contaminated oil. It is thus not possible, in a relatively short time, to remove all the PCB oil. The result is that when new, clean oil is placed in the transformer, there is a gradual leaching out of residual PCBs from the porous components. Over a period of weeks, or longer, the measured PCB level in the new transformer oil can slowly rise again, perhaps to above the levels which are legally permitted.

In accordance with the United Nations Environmental Programme (UNEP) guideline “PCB Transformers and Capacitors: From Management to Reclassification and Disposal“, it is estimated that leaching-back effect is to be 10% and the equilibrium is to be established after 90 days of operation of the transformer. Moreover, in accordance with the Canadian Council of Ministries of the Environment (CCME) guideline “PCB Transformer Decontamination Standards and Protocols” the leaching-back percentages associated with various decontamination methods for mineral oil transformers with initial PCB concentrations under 500 ppm are as follows:

* On-line to a mobile chemical treatment unit yields an expected leach-back of approximately 3-5%;
* Hot retrofill (flush) with 1.5 volumes of clean, hot mineral oil has an expected leach-back of approximately 5%;
* Cold retrofill (flush) with one volume of clean mineral oil performed 3 times has an expected leach-back of approximately 10%;
* Cold retrofill with one volume of clean mineral oil has an expected leach-back of approximately 15%;

In some cases it may be necessary to carry out several retrofilling operations and this over several months.

A decision about the viability of doing a retrofilling operation will take into consideration several factors:

* the cost of carrying out the retrofilling operation, including disposal costs for the contaminated materials, to be set against the cost of buying a new transformer, if the original one is discarded;
* the remaining expected life-time;
* the condition of the transformer;
* the special design of the transformer that limits immediate availability of the replacement one;
* availability of suitable replacement fluids;
* elimination the waste transformer oil and other waste generated by the retrofilling;
* number of repeated retrofilling operations.

# Disposal Scenarios for the PCB-contaminated Transformers

Several scenarios for the disposal of the PCB-contaminated transformers have been envisaged, by taking into consideration several factors, like: the PCB concentration; the life-cycle management, i.e. re-use of the transformer after the treatment; possibilities for export of the PCB-containing transformers to the available treatment facilities in the region; possibilities for leasing of the unit for the treatment in Montenegro, etc.

The following scenarios are considered:

1. Export and final disposal of the PCB contaminated transformers is considered in two variants:
2. Export and incineration of complete PCB contaminated equipment;
3. Export and treatment of complete PCB contaminated equipment.
4. Retrofilling followed by export and incineration of PCB contaminated oil and cellulosic material from disposed-off transformers, while the equipment will be returned to operation or disassembled;
5. The dehalogenation scenario is considered in three variants:
6. Purchasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP) in the country;
7. Leasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP);
8. Export of the PCB-containing transformers for treatment abroad and returning the treated transformers back for re-use.

Moreover, separate analyses on the cost estimates have been made for the specially designed transformers from KAP with high PCB concentrations. Two disposal scenarios have been taken into consideration: A. Export for incineration of the entire transformer and B. Retrofilling in order to define the option which is economically more acceptable.

## Scenario I – Export and final disposal of the PCB contaminated transformers

This scenario envisions the export of complete equipment and oils contaminated with PCBs, i.e. from low to very high concentrations of PCB, the so-called “pure” PCB transformers. The current practices for the disposal of this kind of transformers are by exporting them abroad.

Scenario I envisages two sub-categories:

1. Export and incineration of complete PCB contaminated equipment;
2. Export and treatment of complete PCB contaminated equipment.

Scenario I for the both sub-categories includes:

* Purchase a "new" transformer, without PCB;
* Removing the old transformer from the network, its packaging in a proper manner, transport of hazardous waste to the location of the operator having a permit for temporary storage of hazardous waste and export abroad to the final disposal in accordance with the Basel Convention and the applicable international transportation agreements;
* Installing a “new” transformer and plugging in the network.

The global benefit of this scenario is that the environmental risks are minimized due to the fact that on-site operations will be limited to repacking activities only (i.e. draining of transformers and packing of the oil in appropriate packages). Moreover, since this scenario requires purchasing of new transformers, the energy consumption, i.e. the losses of the energy will be reduced due to the higher efficiency of the new transformers in comparison to the old ones.

## Scenario ii – retrofilling followed by export and incineration

Scenario II implies retrofilling of the low PCB-containing transformers intended for re-use and those for recycling. The process of retrofilling is basically draining the PCB-containing oil, refilling the transformers for re-use with non-PCB oil and export of the drained PCB contaminated oil for final disposal; while for the PCB-containing transformers intended for recycling, flushing the unit with non-PCB containing mineral oil followed by the export of PCB contaminated oil and cellulosic material from finally disposed-off units. In the case of “end of life”, next to the oil, cellulosic material is also to be exported for disposal, while the remaining parts (metals) are dismantled and used as a secondary raw materials. This approach is valid only for the low PCB contaminated transformers intended for recycling for which the practice demonstrates the feasibility of the washing, flushing of the transformer carcasses with hot oil in reaching the limit values of the metal parts of up to 10µg/100 cm2, while for the “pure” PCB containing transformers flushing/rinsing with solvent is required.

Scenario II includes the following activities:

For transformers for re-use

* Draining of the PCB contaminated transformers;
* Packing the drained PCB oil in a proper manner, transport of hazardous waste to the location of the operator having a permit for temporary storage and export abroad to the final disposal in accordance with the Basel Convention and the applicable international transportation agreements;
* Re-filling the drained transformers with non-PCB transformer oil.

For disposed-off transformers

* Purchase a "new" transformer;
* Removing the old transformer from the network, its packaging in a proper manner, transport of hazardous waste to the location of the operator having a permit for temporary storage;
* Flushing and dismantling of transformer, taking into account that PCB containing materials later go into different waste flows for reuse in accordance with national regulations;
* The rest of hazardous waste export abroad to the final disposal in accordance with the Basel Convention and the applicable international transportation agreements;
* Installing a new transformer and plugging in the network.

In this way the project may be able to decrease the disposal costs for transformer owners or operators.

The retrofilling operations for the both types of transformers (for re-use and disposed-off) may be carried out only by experienced company authorized by the responsible institution in the country.

## Scenario III - Dehalogenation

Scenario III provides for the treatment of PCB oil (with a lower PCB content - below 2,000 ppm) in the existing transformer, at a PCB treatment facility with a technique and approach that is found to be more optimal for national conditions.

By taking into consideration the safety aspects of the dehalogenation process and the risk of fire or explosion associated with the usage of sodium, lithium and the derivatives, the following dehalogenation technologies have been considered as the most optimal ones:

* Potassium Hydroxide PEG dehalogenation process (KPEG process)
* Continuous Dehalogenation Process (CDP Process)

This scenario envisages three sub-categories:

1. Purchasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP) in the country;
2. Leasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP);
3. Export of the PCB-containing transformers for treatment abroad, i.e. in the established treatment facilities in the Balkan region and returning the treated transformers back for re-use.

The advantage of this scenario can be great for transformer owners, as in this way the costs that are necessary to complete the conditions defined by the Stockholm Convention and national regulations on PCBs are significantly reduced. Mainly this is due to the ability of the technology that after the PCB-containing transformers have been treated the same can be reused or returned in service. This prolongs the lifetime of the transformer and reduces the cost of purchasing new one.

# Cost-Benefit Analysis on the Disposal Scenarios

This section quantifies the expected costs for the disposal scenarios elaborated in the previous section, demonstrating the most feasible option for the disposal of the PCB-contaminated transformers. Moreover, having in mind larger quantities of high concentrated PCB containing transformers within the industrial sector, separate analysis on cost estimates for different disposal scenarios for these transformers was performed (see chapter 6).

The input data and the assumptions used for estimation of the costs for the respective scenarios are presented in the Table 3.

Table 3: Input data and assumptions for the cost estimations

|  |  |  |
| --- | --- | --- |
| **Input data** |  | **Note** |
| **Number of PCB contaminated transformers, No** | 68 |  |
| **Weight of the PCB oil, kg** | 23,550 |  |
| **Total weight of the PCB contaminated transformers, kg** | 102,852 |  |
| **Contaminated transformers, %** | 1.51 for stationary transformers  1.01 for pole mounted transformers | 79.5% < 500 ppm; 12.8% ≥ 500 ppm, 7.7% > 2,000 ppm  100% < 500 ppm |
| **Average life, years** | 40 |  |
| **Disposal deadline** | 2025 |  |
| **Remaining useful life, years** | 5 | The assumed lifetime of a transformer is 40 years. The replacement costs for the identified PCB-containing transformers have been calculated (see Annex 2). For the PCB-containing transformers with unknown year of production and for the PCB-containing transformers estimated to be identified it is assumed remaining useful life of 5 years. |
| **Interest rate, %/year** | 6.17 | Weighted average lending interest rate of the Central Bank of Montenegro as of 06.11.2019 |
| **The price of a new transformer oil €/kg** | 3.0 | 2.5 – 3.2 |
| **Price of new transformer, €**  **50 kVA**  **100 kVA**  **160 kVA**  **250 kVA**  **400 kVA**  **630 kVA**  **1000 kVA**  **1250 kVA**  **2500 kVA** | 2,000  2,500  3,500  4,500  6,200  8,000  9,500  11,500  20,000 |  |
| **De-installation/re-installation costs of transformers** | 200 |  |
| **Disassemble of transformers** | 150 | Including flushing and components separation |
| **Price of new transformer oil, €/kg** | 3.0 |  |
| **Price of treated transformer oil returned back into the transformers intended for reuse, €/kg** | 1.5 |  |
| **Price of disposal of the waste oil ≤ 50 ppm PCB, €/kg** | 1.5 | The waste oil with ≤ 50 ppm of PCBs will be exported for disposal |
| **Weight fraction of copper in transformer, %** | 13.5 | 13 – 14% |
| **Price of copper, €/kg** | 4.0 | Average price received from scrap dealers |
| **Cellulose material, %** | 8.0 | 6 – 8% |
| **Leaching back - retrofilling (%)** | 10 | 10-15% |
| **Leaching-back – after treatment (%)** | 3 | 3-5% |
| **Transport of PCB materials, €/t** | 250  150 | Within western EU countries (distance up to 2,000 km)  Within Balkan region (distance up to 500 km) |
| **Transport permits, insurances, €/t** | 200 |  |
| **Packing of PCB materials, €/t** | 450 | Including pumping, packing, packages, health and safety equipment |
| **Transformers incineration price, €/t equipment** | 900 |  |
| **PCB transformer carcass treatment** | 300 | The transformers previously drained and transported empty to the treatment facility |
| **The price of oil and cellulose incineration, €/t** | 750 |  |
| **Management costs** | 10% | 10-15% |

## Scenario I – Export and final disposal of complete PCB-contaminated transformers

1) export and incineration of complete pcb-contaminated transformers

**Assumptions:**

* It is assumed that the PCB-contaminated transformers are disposed-off by the incineration facility abroad;
* The assumed maximum lifetime of the transformer for the needs of this analysis is 40 years. In the EU this is 30 years. The replacement costs for the identified PCB-containing transformers have been calculated (see Annex 2). For the PCB-contaminated transformers with unknown year of production (12 pieces) and for the PCB-contaminated transformers estimated to be identified (7 pieces) it is assumed remaining useful life of 5 years. Majority of the PCB-contaminated transformers with known year of production (around 67%) are older than 40 years and there will be no techno-economic feasibility for further operational use and that in any case they would be disassembled. A definitive decision in practice will depend on the decision of the equipment owner;
* The prices of new transformers in accordance to their capacities are presented in the Table 3.

**Advantages:**

* The easiest to organize scenario;
* The minimum risk for the project implementation;
* Complete organization and implementation can be left to the operator with references;
* Cost estimation is very reliable.

**Disadvantages:**

* The most expensive scenario;
* It requires transboundary transport, which can be a very complex and long-lasting job;
* Transformer oil is not regenerated, i.e. the same is burned;
* There is no recovery of the secondary raw materials, since the same are melted and form a slug.
* The "proximity principle" of the waste management policy is not respected according to which the waste should be disposed of near the their source;
* "Principle of self-sufficiency" of the waste management policy is not respected, according to which the country should be capable to dispose its own waste using their own capacities.

The cost estimates for this scenario are provided in the Table 4.

Table 4: Cost estimates for the scenario I.1 – Export and incineration of complete PCB-contaminated transformers

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity** | **Amount of PCB contaminated equipment** | **Price (€/t)** | **Sum (€)** | **Note** |
| **Number of transformers** | 68 |  |  |  |
| **Weight of oil (tons)** | 23.55 |
| **Total weight (tons)** | 102.85 |
| **De-installation costs of transformers (pieces)** | 63 | 200 | 12,600 | Five transformers are already disposed-off, therefore 63 transformers will need to be de-installed |
| **Packing of the PCB materials (tons)** | 102.85 | 450 | 46,283 | The price Includes pumping, packing, packages, health and safety equipment |
| **Transport of the PCB materials (tons)** | 102.85 | 450 | 46,283 | The price includes preparation of documentation, permits, insurances, loading/unloading and transport |
| **The price of the PCB transformer carcass incineration (tons)** | 79.3 | 900 | 71,370 | Including the cellulose material |
| **The price of PCB oil incineration (tons)** | 23.55 | 750 | 17,663 |  |
| **Replacement costs** |  |  | 74,736 | It is assumed that 33 transformers due to their age and general condition, by the end of the disposal deadline will reach the end of their useful life, which means that the remaining 35 transformers will need to be replaced as a result of the project, by taking into consideration the remaining useful life of the removed transformers specified by the owner and the prices of the new transformers as per Table 3 (see the calculations in Annex 2). |
| **Installing a “new” transformer** | 63 | 200 | 12,600 |  |
| **Management costs** |  |  | 22,978 | The management costs are estimated to 10% of the value of the disposal activities |
| **TOTAL (€)** |  |  | **304,511** |  |

2) export and treatment of complete pcb-contaminated transformers

**Assumptions:**

* It is assumed that the PCB contaminated transformers are completely disposed-off by the treatment facility abroad using solvent decontamination or thermal desorption for the metal parts and incineration for the PCB-containing oil and the porous materials;
* The assumed maximum lifetime of the transformer for the needs of this analysis is 40 years. In the EU this is 30 years. The replacement costs for the identified PCB-containing transformers have been calculated (see Annex 2). For the PCB-containing transformers with unknown year of production (12 pieces) and for the PCB-containing transformers estimated to be identified (7 pieces) it is assumed remaining useful life of 5 years. Majority of the PCB-containing transformers with known year of production (around 67%) are older than 40 years and there will be no techno-economic feasibility for further operational use and that in any case they would be disassembled. A definitive decision in practice will depend on the decision of the equipment owner;
* The prices of new transformers in accordance to their capacities are presented in the Table 3.

**Advantages:**

* The easiest to organize scenario;
* The minimum risk for the project implementation;
* Complete organization and implementation can be left to the operator with references;
* Cost estimation is very reliable;
* The costs for the final disposal are reduced due to the revenues of the secondary raw materials (copper, iron).

**Disadvantages:**

* It requires transboundary transport, which can be a very complex and long-lasting job;
* Transformer oil is not regenerated, i.e. the same is burned;
* The "proximity principle" of the waste management policy is not respected according to which the waste should be disposed of near the their source;
* The "Principle of self-sufficiency" of the waste management policy is not respected, according to which the country should be capable to dispose its own waste using their own capacities.

The cost estimates for this scenario are provided in the Table 5.

Table 5: Cost estimates for the scenario I.2 – Export and treatment of complete PCB-contaminated transformers

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity** | **Amount of PCB contaminated equipment** | **Price (€/t)** | **Sum (€)** | **Note** |
| **Number of transformers** | 68 |  |  |  |
| **Weifgt of oil (tons)** | 23.55 |
| **Total weignt (tons)** | 102.85 |
| **De-installation of transformers** | 63 | 200 | 12,600 | Five transformers are already disposed-off, therefore 63 transformers will need to be de-installed |
| **Packing of the PCB materials (tons)** | 102.85 | 450 | 46,283 | The price Includes pumping, packing, packages, health and safety equipment |
| **Transport of the PCB materials (tons)** | 102.85 | 450 | 46,283 | The price includes preparation of documentation, permits, insurances, loading/unloading and transport |
| **The price of the PCB transformers carcass treatment (tons)** | 79.3 | 300 | 23,790 |  |
| **The price of cellulose incineration (tons)** | 8.2 | 750 | 6,150 | After the treatment, the treatment facility disassembles the transformer carcass, separate the cellulose and send the same for incineration. The cellulose material is estimated to 8.0% compared to the mass of equipment. (102.85 X 8% = 8.23 t of waste cellulosic material). |
| **The price of PCB oil incineration (tons)** | 23.55 | 750 | 17,663 |  |
| **Replacement costs** |  |  | 74,736 | It is assumed that 33 transformers due to their age and general condition, by the end of the disposal deadline will reach the end of their useful life, which means that the remaining 35 transformers will need to be replaced as a result of the project, by taking into consideration the remaining useful life of the removed transformers specified by the owner and the prices of the new transformers as per Table 3. |
| **Installing a “new” transformer** | 63 | 200 | 12,600 |  |
| **Management costs** |  |  | 18,374 | The management costs are estimated to 10% of the value of the disposal activities |
| **TOTAL (€)** |  |  | **258,478** |  |

## Scenario ii – retrofilling followed by export and incineration

**Assumptions:**

* In accordance with the Rulebook on Waste Oil Management (OGM 48/12) the waste oil containing PCBs up to 50 ppm can be refined by authorized companies; the waste oil containing PCB up to 5 ppm can be regenerated by authorized companies; and the waste oil containing PCB up to 10 ppm can be burned in authorized facilities for waste incineration. Since currently there are no capacities in the country to refine, regenerate and burn the waste oil, the same is to be exported for disposal.
* Before dismantling the transformer in order to separate the different waste fractions (oil, cellulose, etc.) and their subsequent incineration, it is necessary first to decontaminate, i.e. to wash/flush the interior of the transformers;
* The assumed maximum lifetime of the transformer for the needs of this analysis is 40 years. In the EU this is 30 years. The replacement costs for the identified PCB-containing transformers have been calculated (see Annex 2). For the PCB-containing transformers with unknown year of production (12 pieces) and for the PCB-containing transformers estimated to be identified (7 pieces) it is assumed remaining useful life of 5 years. Majority of the PCB-containing transformers with known year of production (around 67%) are older than 40 years and there will be no techno-economic feasibility for further operational use and that in any case they would be disassembled. A definitive decision in practice will depend on the decision of the equipment owner;
* The prices of new transformers in accordance to their capacities are presented in the Table 3;
* It is assumed that there is experienced company authorized by the responsible institution in the country that can perform the retrofilling operations (draining, re-filling, dismantling, washing, packing, etc.) for the both types of transformers (for re-use and disposed-off) in a safe manner.

**Advantages:**

* The costs of transport and incineration are reduced in relation to the scenario with the export of complete contaminated equipment;
* The revenue of the metal parts (copper) that remain as secondary raw materials reduce the cost of treatment;
* Part of the transformers after the treatment returns to exploitation until the "end of life". This is especially valuable for the special designed transformers for which there is no readily available replacements on the market;
* The "proximity principle" of the waste management policy is partly respected as only one portion of the waste is to be exported for disposal.

**Disadvantages:**

* Decontamination of equipment is performed by retrofilling with new oil which is increasing the amount of PCB contaminated oil and materials to be sent to the incineration. Since the leaching back effect is estimated to 10-15% from the initial concentration of the PCB in the oil, the transformers with a content of PCB of 500-5,000 ppm will require a double re-filling. Depending on limit set for the treatment (5, 10 or 50 ppm) the number of retrofilling cycles may increase and consequently it will affect the management practices of the waste oil (the same can be either refined, regenerated or burned);
* The retrofilling operations are carried out in the country by some authorized company and without following the best working practices the risk of incidents is very high;
* The retrofilling process has a disadvantage as the amount of waste material increases, which generally is not in accordance with the basic ecological principles (not increasing the amount of waste);
* Transformer oil is not regenerated, i.e. the same is burned;
* A new transformer oil is needed for the transformers that are to be reused;
* The "Principle of self-sufficiency" of the waste management policy is not respected, according to which the country should be capable to dispose its own waste using their own capacities.

The cost estimates for this scenario having in mind the limit values of the PCB content in the oil after the retrofilling of up to 10 and up to 50 ppm are provided in the Table 6.

Table 6: Cost estimates for the scenario II – Retrofilling followed by export and incineration

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity** | **Amount of PCB contaminated equipment** | **Price**  **(€/t)** | **Sum**  **(€)** | **Note** |
| **Disposed-off transformers** **:** | | | | |
| **Number of transformers** | 5 |  |  |  |
| **Weight of oil (tons)** | 2.2 |
| **Total weight (tons)** | 7 |
| **Draining of transformers** | 5 | 150 | 750 | The price includes pumping of the oil from the transformers in appropriate packages and transportation of the same to the temporary storage |
| **Required oil for washing of the disposed-off transformer carcasses (tons)** | 2.2 | 3,000 | 6,600 | The empty transformer carcasses are to be flushed with one volume of clean hot oil and disassembled |
| **Disassemble of transformers** | 5 | 150 | 750 | Including flushing and components separation. It is assumed that 5 transformers are to be disposed-off. |
| **Packing of the PCB oil and the cellulose material (tons)** | 2.8 | 450 | 1,260 | The price Includes pumping, packing, packages, health and safety equipment. The cellulose material is estimated to 8.0% compared to the mass of equipment. (7.0 X 8% = 0.6 t of waste cellulosic material). |
| **Transport of the PCB oil and the cellulose material (tons)** | 2.8 | 450 | 1,260 | The price includes preparation of documentation, permits, insurances, loading/unloading and transport |
| **Incineration of the drained transformer oil and the cellulose material (tons)** | 2.8 | 750 | 2,100 |  |
| **Copper (13,5%)** | 0.95 | -4,000 | -3,780 | 13.5% compared to the mass of equipment is used as secondary raw material (7.03 X 13,5% = 0.95 t). Other secondary raw materials are not counted at this stage. |
| **Flushing of the empty transformer carcasses** | 5 | 100 | 500 |  |
| **Price of flushed oil used for washing** | 2.2 | 1,500 | 3,300 | The flushed oil is assumed to have PCB concentration up to 50 ppm and to be exported for disposal. |
| **Transformers for reuse:** | | | | |
| **Number of transformers** | 63 |  |  |  |
| **Weight of oil (tons)** | 21.4 |
| **Total weight (tons)** | 95.8 |
| **Draining of transformers and refilling with new oil to up to 50 ppm** | 81 | 150 | 12,150 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 50 ppm, 58 PCB contaminated transformers will be retrofilled once, 7 transformers will be retrofilled twice and 3 transformers three times (all in total there will be 81 retrofillings), see Annex 3. |
| **Required new transformer oil for retrofilling of transformers to up to 50 ppm (tons)** | 26.6 | 3,000 | 79,800 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 50 ppm, the quantities of the new oil used in the retrofilling process is calculated to 26.6 tons. |
| **Installation/de-installation of degasifying unit** | 1 | 10,000 | 10,000 |  |
| **Degasifying of the oil prior retrofilling up to 50 ppm** | 26.6 | 500 | 13,300 |  |
| **Analytical costs (chemical and electrical properties) up to 50 ppm** | 81 | 250 | 20,250 |  |
| **Packing of the drained PCB oil up to 50 ppm (tons)** | 26.6 | 450 | 11,970 |  |
| **Transport of the drained PCB oil up to 50 ppm (tons)** | 26.6 | 450 | 11,970 |  |
| **Incineration of the drained transformer oil up to 50 ppm (tons)** | 26.6 | 750 | 19,950 |  |
| **Draining of transformers and refilling with new oil to up to 10 ppm** | 93 | 150 | 13,950 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 10 ppm, 47 PCB contaminated transformers will be retrofilled once, 18 transformers will be retrofilled twice, 2 transformers three times and 1 transformers four times (all in total in total there will be 93 retrofillings), see Annex 4. |
| **Required new transformer oil for retrofilling of transformers to up to 10 ppm (tons)** | 30.8 | 3,000 | 92,400 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 10 ppm, the quantities of the new oil used in the retrofilling process is calculated to 30.8 tons. |
| **Degasifying of the oil prior retrofilling up to 10 ppm** | 30.8 | 500 | 15,400 |  |
| **Analytical costs (chemical and electrical properties) up to 10 ppm** | 93 | 250 | 23,250 |  |
| **Packing of the drained PCB oil up to 10 ppm (tons)** | 30.8 | 450 | 13,860 |  |
| **Transport of the drained PCB oil up to 10 ppm (tons)** | 30.8 | 450 | 13,860 |  |
| **Incineration of the drained transformer oil up to 10 ppm (tons)** | 30.8 | 750 | 23,100 |  |
| **Price of drained oil at the end of the service life up to 50 ppm** | 21.4 | 1,500 | 32,100 | It is assumed that oil that was used for the final retrofilling of the transformers will have PCB concentration of up to 50 ppm at the end of the service life and to be exported for disposal. |
| **Disassemble of transformers at the end of the service life** | 63 | 150 | 9,450 | Including flushing and components separation |
| **Waste material (cellulose), t** | 7.7 | 1,450 | 11,113 | 8.0% compared to the mass of equipment. (95.8 X 8% = 7.7 t of waste cellulosic material). The price includes packing, transportation and incineration |
| **Copper 13.5%w, €/kg** | 12.93 | -4,000 | -51,732 | 13.5% compared to the mass of equipment is used as secondary raw material (95.8 X 13,5%= 12.93 t ). Other secondary raw materials are not counted at this stage. |
| **Management costs (for up to 50 ppm)** |  |  | 20,325 | The management costs are estimated to 10% of the value of the disposal activities |
| **Management costs (for up to 10 ppm)** |  |  | 22,695 | The management costs are estimated to 10% of the value of the disposal activities |
| **TOTAL (€) to 50 ppm** |  |  | **213,386** |  |
| **TOTAL (€) to 10 ppm** |  |  | **242,186** |  |

## Scenario III - Dehalogenation

**Assumptions:**

* All cellulosic material at the end of the working life is sent to the incineration;
* All metal material at the end of the working life is used as a secondary raw material;
* Transformer oil is regenerated with a yield of 95% and reuse;
* The assumed maximum lifetime of the transformer for the needs of this analysis is 40 years. In the EU this is 30 years. The replacement costs for the identified PCB-containing transformers have been calculated (see Annex 5). For the PCB-containing transformers with unknown year of production (12 pieces) and for the PCB-containing transformers estimated to be identified (7 pieces) it is assumed remaining useful life of 5 years. Majority of the PCB-containing transformers with known year of production (around 67%) are older than 40 years and for these transformers the remaining useful life is set to 5 years. A definitive decision in practice will depend on the decision of the equipment owner;
* The cost of transporting the transformer to the location for decontamination is not shown and it is assumed that it is the cost for equipment owners;
* The proportion of PCB transformers with PCB content over 500 mg is assumed to be 12% (based on the current inventory results). The scenario will be presented in two variants: PCB content after treatment of 10 ppm and 50 ppm;
* Processed oil at the end of the working life is burned in the waste incineration facility (up 10 ppm of PCB) or is regenerated (up to 5 ppm of PCB) or refined (up to 50 ppm of PCB);
* The prices of new transformers in accordance to their capacities are presented in the Table 3;
* After the decontamination, the transformers will be subjected to basic servicing, thus prolong their useful life for 7 years;
* The costs of renting the space required for the treatment unit are calculated for 6 months;
* The costs for the treatment of the transformers with different PCB content to 50 or to 10 ppm are average ones from several technology providers.

1) Purchasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP) in the country

**Advantages:**

* Dehalogenation technology has been proven and tested in practice;
* Avoidance of transboundary transport of complete contaminated PCB equipment with all problems that accompany it during transportation and preparation;
* Ability of the technology that after the PCB-containing transformers have been treated the same can be reused or returned in service. This prolongs the lifetime of the transformer and reduces the cost of purchasing new one;
* The revenue of the metal parts (copper) that remain as secondary raw materials and the reusing of the treated oil for the disposed of transformers reduce the cost of treatment;
* Sustainability for the future decontamination is secured;
* The "proximity principle" of the waste management policy is respected according to which the waste should be disposed of near the their source;
* The "Principle of self-sufficiency" of the waste management policy is respected, according to which the country should be capable to dispose its own waste using their own capacities.

**Disadvantages:**

* Cost of investment in new plant;
* The time period from decision-making to commissioning is unknown (about 1 year for tender, contracting, design, procurement, production, delivery, assembly and commissioning and performance demonstration). In addition, the procedure (time) of obtaining the necessary operational and environmental permits is about 6 months;
* Necessary training of operators for work with new plant;
* Higher level of responsibility of the Operator related to the guarantees for the successfulness of the treatment and the prevention/mitigation of the risk during the operation.

2) Leasing of the treatment unit (stationary one) with a capacity of 1.0 tons/day (KPEG or CDP)

**Advantages:**

* Dehalogenation technology has been proven and tested in practice;
* The decontamination is performed by experienced company, reducing the level of risk associated with the operation of the technology;
* Avoidance of transboundary transport of complete contaminated PCB equipment with all problems that accompany it during transportation and preparation;
* Ability of the technology that after the PCB-containing transformers have been treated the same can be reused or returned in service. This prolongs the lifetime of the transformer and reduces the cost of purchasing new one;
* The revenue of the metal parts (copper) that remain as secondary raw materials and the reusing of the treated oil for the disposed of transformers reduce the cost of treatment;
* The "proximity principle" of the waste management policy is respected according to which the waste should be disposed of near the their source;

**Disadvantages:**

* Costs of installation/de-installation of the technology;
* The procedure (time) of obtaining the necessary operational and environmental permits is about 6 months;
* The "Principle of self-sufficiency" of the waste management policy is not respected, according to which the country should be capable to dispose its own waste using their own capacities.
* Sustainability for the future decontamination is not secured;

3) Export of the PCB-containing transformers for treatment abroad and returning the treated transformers back for re-use

**Advantages:**

* Dehalogenation technology has been proven and tested in practice;
* Complete organization and implementation can be left to the operator with references;
* No operational risks in the country as the transformers are to be treated abroad;
* Ability of the technology that after the PCB-containing transformers have been treated the same can be reused or returned in service. This prolongs the lifetime of the transformer and reduces the cost of purchasing new one.
* The revenue of the metal parts (copper) that remain as secondary raw materials and the reusing of the treated oil for the disposed of transformers reduce the cost of treatment;

**Disadvantages:**

* It requires transboundary transport, which can be a very complex and long-lasting job;
* The "proximity principle" of the waste management policy is not respected according to which the waste should be disposed of near the their source;
* The "Principle of self-sufficiency" of the waste management policy is not respected, according to which the country should be capable to dispose its own waste using their own capacities;
* The transport of transformers to the disposal site and back to Montenegro will increase the overall costs;

The cost estimates for this scenario having in mind the three variants and the limit values of the PCB content in the oil after the decontamination of up to 10 and up to 50 ppm are provided in the Table 7.

Table 7: Cost estimates for the scenario III – Dehalogenation

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Activity** | **Quantity** | **Cost of treatment €/t of equipment** | **SCENARIO 1:** | **SCENARIO 2:** | **SCENARIO 3:** | **Note** |
| **Purchasing of the treatment unit** | **Leasing of the treatment unit** | **Export of the PCB-containing transformers for treatment abroad and returning the treated transformers back for re-use** |
| **Number of transformers** | 68 |  |  |  |  |  |
| **Total PCB equipment, t** | 102.85 |  |  |  |  |  |
| **PCB contaminated oil, t** | 23.55 |  |  |  |  |  |
| **PCB transformers with PCB concentration < 500 ppm** | 84.15 |  |  |  |  |  |
| **PCB equipment with PCB concentration ≥ 500 ppm** | 18.70 |  |  |  |  |  |
| **Cost of treatment transformers with PCB concentration between 50-500 ppm to 50 ppm** | 84.15 | 2,000 | 168,300 | 185,130 | 151,470 | The operating costs include: reagents, laboratory analyses, manpower, disposal of the by-products, new oil needed to supplement the one which is spent in the reaction (around 5-10%), re-conditioning of the transformers intended for re-use |
| 2,200 |
| 1,800 |
| **Cost of treatment transformers with PCB concentration < 500 ppm to 10 ppm** | 84.15 | 2,100 | 176,715 | 193,545 | 159,885 | The operating costs include: reagents, laboratory analyses, manpower, disposal of the by-products, new oil needed to supplement the one which is spent in the reaction (around 5%), re-conditioning of the transformers intended for re-use |
| 2,300 |
| 1,900 |
| **Cost of treatment transformers with PCB concentration ≥ 500 ppm to 50 ppm** | 18.70 | 2,100 | 39,270 | 43,010 | 35,530 | The operating costs include: reagents, laboratory analyses, manpower, disposal of the by-products, new oil needed to supplement the one which is spent in the reaction (around 5%), re-conditioning of the transformers intended for re-use |
| 2,300 |
| 1,900 |
| **Cost of treatment transformers with PCB concentration ≥ 500 ppm to 10 ppm** | 18.70 | 2,200 | 41,140 | 44,880 | 37,400 | The operating costs include: reagents, laboratory analyses, manpower, disposal of the by-products, new oil needed to supplement the one which is spent in the reaction (around 5%), re-conditioning of the transformers intended for re-use |
| 2,400 |
| 2,000 |
| **Cost for re-treatment of transformers up to 50 ppm** | 4.4 | 2,000 | 2,200 | 2,420 | 7,920 | All transformers with initial concentration between 1,700-55,000 ppm will be subjected for re-treatment once (4.4 tons). |
|  |  | 2,200 |  |  |  |  |
|  |  | 1,800 |  |  |  |  |
| **Cost for re-treatment of transformers up to 10 ppm** | 19.8 | 2,100 | 9,870 | 10,810 | 37,620 | All transformers with initial concentration between 400-11,000 ppm will be subjected for re-treatment once (17.4 tons), while above 11,000 twice (2.4 tons). |
|  |  | 2,300 |  |  |  |  |
|  |  | 1,900 |  |  |  |  |
| **Price of the treatment unit** |  |  | 350,000 |  |  |  |
| **Costs for renting of a space for the treatment unit** | 6 | 2,000 | 12,000 | 12,000 |  | It is assumed that treatment of the transformers will take 6 months and renting cost of a space of 400m2 is 2,000 Eur/month |
| **Costs for the installation of the treatment unit** |  |  | 30,000 | 30,000 |  |  |
| **Costs for the de-installation of the treatment unit** |  |  |  | 30,000 |  |  |
| **De-installation costs for the transformers** | 63 | 200 | 12,600 | 12,600 | 12,600 | Five transformers are already disposed-off, therefore 63 transformers will need to be de-installed |
| **De-installation costs for the transformers that were re-treated up to 10 ppm** | 11 | 200 | 2,200 | 2,200 | 2,200 | From the re-treated transformers (10 pieces), 9 will be de-installed once and 1 twice (11 de-installations) |
| **De-installation costs for the transformers that were re-treated up to 50 ppm** | 3 | 200 | 600 | 600 | 600 | All 3 re-treated transformers are to be de-installed once |
| **The value of the treated transformer oil returned back into the transformers intended for reuse** | 22.37 | -1,500 | -33,559 | -33,559 | -33,559 | 95% of the regenerated transformer oil after treatment has the characteristic of re-usable transformer grade oil, with the value of 1,500 Euro per ton (23.55 X 95% = 22.37) |
| **Transport of transformers for treatment abroad** | 102.85 | 450 |  |  | 46,283 |  |
| **Returning of the treated transformers back** | 102.85 | 100 |  |  | 10,285 |  |
| **Transport of transformers for re-treatment abroad up to 10 ppm** | 19.8 | 450 |  |  | 8,910 | All transformers with initial concentration between 400-11,000 ppm will be subjected for re-treatment once (17.4 tons), while above 11,000 twice (2.4 tons). |
| **Returning of the re-treated transformers up to 10 ppm back** | 19.8 | 100 |  |  | 1,980 |  |
| **Transport of transformers for re-treatment abroad up to 50 ppm** | 4.4 | 450 |  |  | 1,980 | All transformers with initial concentration between 1,700-55,000 ppm will be subjected for re-treatment once (4.4 tons). |
| **Returning of the re-treated transformers up to 50 ppm back** | 4.4 | 100 |  |  | 440 |  |
| **Re-installation costs for the transformers** | 63 | 200 | 12,600 | 12,600 | 12,600 |  |
| **Re-installation costs for the transformers that were re-treated up to 10 ppm** | 11 | 200 | 2,200 | 2,200 | 2,200 | From the re-treated transformers (10 pieces), 9 will be re-installed once and 1 twice (11 re-installations) |
| **Re-installation costs for the transformers that were re-treated up to 50 ppm** | 3 | 200 | 600 | 600 | 600 | All 3 re-treated transformers are to be re-installed once |
| **Extension of the service lifetime** | 63 |  |  |  | -120,614 | After the decontamination, the transformers will be subjected to basic servicing, thus prolong their useful life from 5-10 years (see Annex 5). Seven years prolongation is used for the calculation purposes. |
| **Analytical costs (chemical and electrical properties) up to 10 ppm** | 74 | 250 | 18,500 | 18,500 | 18,500 | Fifty three transformers will be tested once, 9 transformers twice and 1 transformer three times |
| **Analytical costs (chemical and electrical properties) up to 50 ppm** | 66 | 250 | 16,500 | 16,500 | 16,500 | Sixty transformers will be tested once, and 3 transformers twice |
| **The price of used transformer oil with PCB content up to 10 ppm** | 23.55 | 1,500 | 35,325 | 35,325 | 35,325 | It is assumed that oil that was used for the final retrofilling of the transformers will have PCB concentration of up to 10 ppm at the end of the service life and to be exported for disposal. |
| **The price of used transformer oil with PCB content up to 50 ppm** | 23.55 | 1,500 | 35,325 | 35,325 | 35,325 | It is assumed that oil that was used for the final retrofilling of the transformers will have PCB concentration of up to 50 ppm at the end of the service life and to be exported for disposal. |
| **Disassemble of transformers at the end of the service life** | 68 | 150 | 10,200 | 10,200 | 10,200 | Including draining and components separation |
| **Copper13,5% wt. Eu/kg** | 13.88 | -4,000 | -55,539 | -55,539 | -55,539 | 13.5% compared to the mass of equipment is used as secondary raw material (102.85 X 13,5%= 13.88 t ). Other secondary raw materials are not counted at this stage. |
| **Waste material (cellulose), t** | 8.23 | 1,450 | 11,931 | 11,931 | 11,931 | 8.0% compared to the mass of equipment. (102.85 X 8% = 8.23 t of waste cellulosic material). The price includes packing, transportation and incineration |
| **Management costs** |  |  | 39,262 | 41,816 | 40,399 | The management costs are estimated to 10% of the value of the disposal activities |
| **Total treatment costs to 50 ppm (€)** |  |  | **694,215** | **398,219** | **184,950** |  |
| **Total treatment costs to 10 ppm (€)** |  |  | **742,480** | **449,564** | **238,605** |  |

# Scenarios for disposal of the PCB-containing transformers in-use from KAP

Detailed inventory of the PCB containing equipment and waste performed in the framework of the GEF-funded project “Comprehensive Environmentally Sound Management of PCBs in Montenegro” implemented by UNDP in 2018 identified 99 PCB-containing transformers at KAP.

Moreover, 34 PCB-containing transformers have been disposed-off in the framework of the same project in the period November- December 2018.

Quantities of the PCB-containing transformers from KAP remaining for disposal are presented in the Table 2, while the categorization of the PCB-containing transformers in accordance with different ranges of PCB contamination is presented in the Annex 1.

The PCB-containing transformers that are already phased-out (35 pieces) are to be exported abroad for final disposal. For the disposal of the remaining 30 PCB-containing transformers that are in-use, an analysis of the disposal scenarios have been performed in order to optimize the costs for the disposal of the same, by taking into consideration several factors, like the high PCB content, the specific design of the transformers and the silicon oil that was used for the retrofilling that was performed on some of the transformers.

Moreover, separate analyses on the cost estimates have been made for the specially designed transformers from KAP with high PCB concentrations. Two disposal scenarios have been taken into consideration: export for incineration of the entire transformer and retrofilling in order to define the option which is economically more acceptable.

The following scenarios are considered:

1. Export and final disposal of the PCB-containing transformers;
2. Retrofilling followed by export and incineration of PCB contaminated oil and re-using of the transformers;

## Scenario A – Export and final disposal of complete PCB-containing transformers

**Assumptions:**

* It is assumed that the PCB-containing transformers are completely disposed-off by the treatment facility abroad using solvent decontamination or thermal desorption for the metal parts and incineration for the PCB-containing oil and the porous materials;
* The assumed maximum lifetime of the transformer for the needs of this analysis is 40 years. In the EU this is 30 years. The expected lifetime is calculated on 5 years (the deadline for the disposal set in the regulation up to 2025 has been taken into consideration). The replacement costs for the identified PCB-containing transformers have been calculated (see Annex 6).
* The prices of new transformers in accordance to their capacities are presented in the Table 3.

**Advantages:**

* The easiest to organize scenario;
* The minimum risk for the project implementation;
* Complete organization and implementation can be left to the operator with references;
* Cost estimation is very reliable;
* The costs for the final disposal are reduced due to the revenues of the secondary raw materials (copper, iron).

**Disadvantages:**

* It requires transboundary transport, which can be a very complex and long-lasting job;
* Transformer oil is not regenerated, i.e. the same is burned.
* The "proximity principle" of the waste management policy is not respected according to which the waste should be disposed of near the their source;
* The "Principle of self-sufficiency" of the waste management policy is not respected, according to which the country should be capable to dispose its own waste using their own capacities.

The cost estimates for this scenario are provided in the Table 8.

Table 8: Cost estimates for the scenario A – Export and treatment of complete PCB-containing transformers

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity** | **Amount of PCB contaminated equipment** | **Price (€/t)** | **Sum (€)** | **Note** |
| **De-installation of transformers** | 30 | 200 | 6,000 |  |
| **Packing of the PCB materials (tons)** | 104.68 | 450 | 47,106 | The price Includes pumping, packing, packages, health and safety equipment |
| **Transport of the PCB materials (tons)** | 104.68 | 450 | 47,106 | The price includes preparation of documentation, permits, insurances, loading/unloading and transport |
| **The price of the PCB transformer's carcass treatment (tons)** | 77.00 | 300 | 23,100 |  |
| **The price of celullose incineration (tons)** | 8.37 | 750 | 6,281 | The treatment facility disassembles the transformer carcass, separate the cellulose and send the same for incineration. The cellulose material is estimated to 8.0% compared to the mass of equipment. (104.68 X 8% = 8.37 t of waste cellulosic material). |
| **The price of PCB oil incineration (tons)** | 27.68 | 750 | 20,760 |  |
| **Replacement costs** |  |  | 78,029 | Thirty transformers in use will need to be replaced by 2025 and therefore the expected life-time is 5 years. The prices of the new transformers are indicated in the Table 3 (see the calculations in Annex 6). |
| **Installing a “new” transformer** | 30 | 200 | 6,000 |  |
| **Management costs** |  |  | 14,806 | The management costs are estimated to 10% of the value of the disposal activities |
| **TOTAL (€)** |  |  | **249,188** |  |

## Scenario B – retrofilling followed by export and incineration

**Assumptions:**

* In accordance with the Rulebook on Waste Oil Management (OGM 48/12) the waste oil containing PCBs up to 50 ppm can be refined by authorized companies; the waste oil containing PCB up to 5 ppm can be regenerated by authorized companies; the waste oil containing PCB up to 10 ppm can be burned in authorized facilities for waste incineration. Since currently there are no capacities in the country to refine, regenerate and burn the waste oil, the same is to be exported for disposal.
* Before dismantling the transformer in order to separate the different waste fractions (oil, cellulose, etc.) and their subsequent incineration, it is necessary first to decontaminate, i.e. to wash/flush the interior of the transformers;
* The assumed maximum lifetime of the transformer for the needs of this analysis is 40 years. In the EU this is 30 years. The replacement costs for the identified PCB-containing transformers have been calculated (see Annex 3). For the PCB-containing transformers with unknown year of production (12 pieces) and for the PCB-containing transformers estimated to be identified (7 pieces) it is assumed remaining useful life of 5 years. Majority of the PCB-containing transformers with known year of production (around 67%) are older than 40 years and there will be no techno-economic feasibility for further operational use and that in any case they would be disassembled. A definitive decision in practice will depend on the decision of the equipment owner;
* The prices of new transformers in accordance to their capacities are presented in the Table 3.
* It is assumed that there is experienced company authorized by the responsible institution in the country that can perform the retrofilling operations (draining, re-filling, dismantling, washing, packing, etc.) for the both types of transformers (for re-use and disposed-off) in a safe manner.

**Advantages:**

* The costs of transport and incineration are reduced in relation to the scenario with the export of complete contaminated equipment;
* The revenue of the metal parts (copper) that remain as secondary raw materials reduce the cost of treatment;
* Part of the transformers after the treatment returns to exploitation until the "end of life". This is especially valuable for the special designed transformers for which there is no readily available replacements on the market;
* The "proximity principle" of the waste management policy is partly respected as only one portion of the waste is to be exported for disposal.

**Disadvantages:**

* Decontamination of equipment is performed by retrofilling with new oil which is increasing the amount of PCB contaminated oil and materials to be sent to the incineration. Since the leaching back effect is estimated to 10-15% from the initial concentration of the PCB in the oil, the transformers with a content of PCB of 500-5,000 ppm will require a double re-filling. Depending on limit set for the treatment (5, 10 or 50 ppm) the number of retrofilling cycles may increase and consequently it will affect the management practices of the waste oil (the same can be either refined, regenerated or burned).
* The retrofilling operations are carried out in the country by some authorized company and without following the best working practices the risk of incidents is very high;
* The retrofilling process has a disadvantage as the amount of waste material increases, which generally is not in accordance with the basic ecological principles (not increasing the amount of waste)
* Transformer oil is not regenerated, i.e. the same is burned;
* A new transformer oil is needed for the transformers that are to be reused.
* The "Principle of self-sufficiency" of the waste management policy is not respected, according to which the country should be capable to dispose its own waste using their own capacities.

The cost estimates for this scenario having in mind the limit values of the PCB content in the oil after the retrofilling of up to 10 and up to 50 ppm are provided in the Table 9.

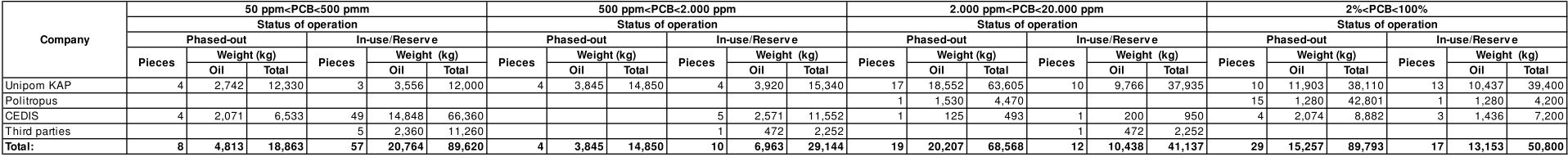
Table 9: Cost estimates for the scenario II – Retrofilling followed by export and incineration

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity** | **Amount of PCB contaminated equipment** | **Price, €** | **Sum, €** | **Note** |
| **Number of transformers** | 30 |  |  |  |
| **Weight of oil (tons)** | 27.7 |
| **Total weight (tons)** | 104.7 |
| **Draining of transformers and refilling with new oil to up to 50 ppm** | 99 | 150 | 14,850 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 50 ppm, 3 PCB contaminated transformers will be retrofilled once, 6 transformers will be retrofilled twice, 10 transformers three times, 1 transformer four times and 10 transformers five times (all in total there will be 99 retrofillings), see Annex 7. |
| **Installation/de-installation of degasifying unit** | 1 | 10,000 | 10,000 |  |
| **Degasifying of the oil prior retrofilling up to 50 ppm** | 84.7 | 500 | 42,350 |  |
| **Analytical costs (chemical and electrical properties) up to 50 ppm** | 99 | 250 | 24,750 |  |
| **Required new transformer oil for retrofilling of transformers to up to 50 ppm (tons)** | 84.7 | 3,000 | 254,100 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 50 ppm, the quantities of the new oil used in the retrofilling proces is calculated to 84.7 tons. |
| **Packing of the drained PCB oil up to 50 ppm (tons)** | 84.7 | 450 | 38,115 |  |
| **Transport of the drained PCB oil up to 50 ppm (tons)** | 84.7 | 450 | 38,115 |  |
| **Incineration of the drained transformer oil up to 50 ppm (tons)** | 84.7 | 750 | 63,525 |  |
| **Draining of transformers and refilling with new oil to up to 10 ppm** | 112 | 150 | 16,800 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 10 ppm, 5 PCB contaminated transformers will be retrofilled twice, 8 transformers will be retrofilled three times, 7 transformers four times and 10 transformers five times (all in totalin total there will be 112 retrofillings), see Annex 8. |
| **Required new transformer oil for retrofilling of transformers to up to 10 ppm (tons)** | 98.8 | 3,000 | 296,400 | Based on the initial concentration of the PCB in the oil and in order to reach PCB concentration up to 10 ppm, the quantities of the new oil used in the retrofilling proces is calculated to 98.8 tons. |
| **Degasifying of the oil prior retrofilling up to 10 ppm** | 98.8 | 500 | 49,400 |  |
| **Analytical costs (chemical and electrical properties) up to 10 ppm** | 112 | 250 | 28,000 |  |
| **Packing of the drained PCB oil up to 10 ppm (tons)** | 98.8 | 450 | 44,460 |  |
| **Transport of the drained PCB oil up to 10 ppm (tons)** | 98.8 | 450 | 44,460 |  |
| **Incineration of the drained transformer oil up to 10 ppm (tons)** | 98.8 | 750 | 74,100 |  |
| **Price of drained oil at the end of the service life up to 50 ppm** | 27.7 | 1,500 | 41,550 | It is assumed that oil that was used for the final retrofilling of the transformers will have PCB concentration of up to 50 ppm at the end of the service life and to exported for dispsoal. |
| **Disassemble of transformers at the end of the service life** | 30 | 150 | 4,500 | Including flushing and components separation |
| **Waste material (cellulose), t** | 8.4 | 1,450 | 12,145 | 8.0% compared to the mass of equipment. (104.7 X 8% = 8.4 t of waste cellulosic material). The price includes packing, transportation and incineration |
| **Copper 13.5%w, €/kg** | 14.13 | -4,000 | -56,538 | 13.5% compared to the mass of equipment is used as secondary raw material (104.7 X 13,5%= 14.13t ). Other secondary raw materials are not counted at this stage. |
| **Management costs (for up to 50 ppm)** |  |  | 57,694 | The management costs are estimated to 10% of the value of the disposal activities |
| **Management costs (for up to 10 ppm)** |  |  | 65,979 | The management costs are estimated to 10% of the value of the disposal activities |
| **TOTAL (€) to 50 ppm** |  |  | **545,157** |  |
| **TOTAL (€) to 10 ppm** |  |  | **631,257** |  |

# Conclusions

In the above treatment scenarios, the most important elements of each of them are shown:

1. Export of the PCB-contaminated transformers for incineration or treatment abroad is comfortable options, but among the most expensive ones (304,511 Euro or 258,478 Euro respectively), especially as it requires procurement of new equipment, which significantly increases the total costs of final disposal;
2. Retrofiling scenario also represent a viable disposal solution for the low PCB-containing transformers, but the identified disadvantages prevents this option to be favorable one. The costs for this scenario, including the both variants for up to 50 and up to 10 ppm, are 213,386 Euro and 242,186 Euro respectively, which significantly reduces costs in relation to scenario I, given that the transformers after the retrofilling remain in operation, and at the end of their useful life, the useful components of the transformers, such as copper and steel, remain in the country returning to recycling;
3. Treatment scenario related to the purchasing of the treatment unit has a number of advantages: avoidance of cross-border transportation of the transformers; the "principle of self-sufficiency" is satisfied according to which each country must ensure that the elimination of waste produced within its territory must be carried out using an environmentally acceptable method; transformers which could be operational are decontaminated and returned to operation, and there is no need to purchase new transformers; cost for decontamination of equipment and treatment of oil is in the country and beneficial for national economy; but the overall quantities of the PCB-containing transformers identified in the country do not justify purchasing of such unit (the investment and the operational cost for the treatment to up to 50 and up to 10 ppm are 694,215 Euro and 742,480 Euro respectively). The leasing option has the same advantages as the former one, whereas the overall costs are estimated to 398,219 Euro for the treatment to up to 50 ppm and 449,564 Euro for the treatment to up to 10 ppm. **The most favorable disposal option in terms of costs, reduction of the operational risks, extension of the transformers life time is the Export of the PCB-containing transformers for treatment abroad, i.e. in the established treatment facilities in the Balkan region and returning the treated transformers back for re-use, with the estimated costs of 184,950 Euro for the treatment to up to 50 ppm and 238,605 Euro for the treatment to up to 10 ppm**.
4. **The most favorable option for the disposal of the specially designed transformers from KAP with high PCB concentrations is** **the Export and final disposal of the PCB-containing transformers with the estimated costs of 249,188 Euro**, in comparison to the Retrofilling option with the estimated costs of 545,157 Euro for the treatment to up to 50 ppm and 631,257 Euro for the treatment to up to 10 ppm.

**Annex 1: PCB-containing transformers categorization from the low-voltage network and the industrial sector remaining for disposal**

**Annex 2: Calculation of the replacement costs**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ord. no.** | **ID** | **Year of production** | **Exp. Life\*\*** | **Capacity kVA** | **Total (kg) per unit** | **Oil (kg) per unit** | **Discount rate** | **Price € new transformer** | **Replacement  costs €** |
| 1 | 03020 | 1981 | 1 | 400 | 270.00 | 1,649.00 | 1.0617 | 6,200 | 360 |
| 2 | 04130 | 1981 | 1 | 400 | 235.00 | 1,280.00 | 1.0617 | 6,200 | 360 |
| 3 | 01874 | 1982 | 2 | 160 | 85.00 | 650.00 | 1.0617 | 3,500 | 395 |
| 4 | 03699 | 1982 | 2 | 630 | 475.00 | 2,450.00 | 1.0617 | 8,000 | 903 |
| 5 | 03700 | 1982 | 2 | 630 | 475.00 | 2,450.00 | 1.0617 | 8,000 | 903 |
| 6 | 06034 | 1983 | 3 | 100 | 125.00 | 575.00 | 1.0617 | 2,500 | 411 |
| 7 | 05543 | 1984 | 4 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 426 |
| 8 | 04128 | 1984 | 4 | 250 | 200.00 | 950.00 | 1.0617 | 4,500 | 958 |
| 9 | 05174 | 1985 | 5 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 517 |
| 10 | 04134 | 1985 | 5 | 250 | 210.00 | 1,090.00 | 1.0617 | 4,500 | 1,164 |
| 11 | 05186 | 1988 | 8 | 250 | 210.00 | 1,090.00 | 1.0617 | 4,500 | 1,713 |
| 12 | 02185 | 2000 | 20 | 630 | 323.00 | 1,826.00 | 1.0617 | 8,000 | 5,584 |
| 13 | 02471 | 2000 | 20 | 630 | 323.00 | 1,833.00 | 1.0617 | 8,000 | 5,584 |
| 14 | 02201 | 2003 | 23 | 630 | 420.00 | 2,010.00 | 1.0617 | 8,000 | 5,981 |
| 15 | 01985 | 2013 | 33 | 1000 | 530.00 | 2,700.00 | 1.0617 | 9,500 | 8,183 |
| 16 | 01463 | 2017 | 37 | 1000 | 580.00 | 2,850.00 | 1.0617 | 9,500 | 8,463 |
| 17 | 01142 | 1985\* | 5 | 250 | 1,004.00 | 2,750.00 | 1.0617 | 4,500 | 1,164 |
| 18 | 01167 | 1985\* | 5 | 250 | 625.00 | 1,845.00 | 1.0617 | 4,500 | 1,164 |
| 19 | 02329 | 1985\* | 5 | 2500 | 2,200.00 | 5,750.00 | 1.0617 | 20,000 | 5,174 |
| 20 | 02540 | 1985\* | 5 | 630 | 323.00 | 1,826.00 | 1.0617 | 8,000 | 2,070 |
| 21 | 02894 | 1985\* | 5 | 1000 | 1,100.00 | 4,300.00 | 1.0617 | 9,500 | 2,458 |
| 22 | 02962 | 1985\* | 5 | 1000 | 1,100.00 | 4,300.00 | 1.0617 | 9,500 | 2,458 |
| 23 | 03071 | 1985\* | 5 | 400 | 270.00 | 1,649.00 | 1.0617 | 6,200 | 1,604 |
| 24 | 01837 | 1985\* | 5 | 400 | 345.00 | 1,540.00 | 1.0617 | 6,200 | 1,604 |
| 25 | 05407 | 1985\* | 5 | 100 | 100.00 | 440.00 | 1.0617 | 2,500 | 647 |
| 26 | 05554 | 1985\* | 5 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 517 |
| 27 | 05586 | 1985\* | 5 | 100 | 110.00 | 415.00 | 1.0617 | 2,500 | 647 |
| 28 | 03729 | 1985\* | 5 | 250 | 235.00 | 1,280.00 | 1.0617 | 4,500 | 1,164 |
| 29 |  | 1985\* | 5 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,070 |
| 30 |  | 1985\* | 5 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,070 |
| 31 |  | 1985\* | 5 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,070 |
| 32 |  | 1985\* | 5 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,070 |
| 33 |  | 1985\* | 5 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,070 |
| 34 |  | 1985\* | 5 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,070 |
| 35 |  | 1985\* | 5 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,070 |
|  | **Total:** | | | | **15,477** | **66,582** |  |  | **74,736** |

\* Transformers with unknown year of production and assumed year of production of 1985

\*\* 40 years are used as average expected life-time of a transformer

**Annex 3: Retrofilling cycles to up to 50 ppm**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ord. no.** | **ID** | **Capacity kVA** | **Total (kg) per unit** | **Oil (kg) per unit** | **PCB**  **(ppm)** | **Retrofilling cycle** | | | **Total** |
| **I** | **II** | **III** |
| 1 | 06508 | 100 | 110.00 | 415.00 | 50.20 | 110.00 |  |  | 110.00 |
| 2 | 01759 | 630 | 540.00 | 2,100.00 | 50.40 | 540.00 |  |  | 540.00 |
| 3 | 01760 | 630 | 540.00 | 2,100.00 | 51.70 | 540.00 |  |  | 540.00 |
| 4 | 05402 | 50 | 100.00 | 440.00 | 51.90 | 100.00 |  |  | 100.00 |
| 5 | 05154 | 50 | 100.00 | 440.00 | 52.00 | 100.00 |  |  | 100.00 |
| 6 | 03393 | 400 | 300.00 | 1,540.00 | 52.30 | 300.00 |  |  | 300.00 |
| 7 | 02375 | 630 | 323.00 | 1,826.00 | 52.40 | 323.00 |  |  | 323.00 |
| 8 | 03428 | 50 | 86.00 | 365.00 | 53.90 | 86.00 |  |  | 86.00 |
| 9 | 03020 | 400 | 270.00 | 1,649.00 | 56.70 | 270.00 |  |  | 270.00 |
| 10 | 01853 | 630 | 540.00 | 2,100.00 | 57.50 | 540.00 |  |  | 540.00 |
| 11 | 03071 | - | 270.00 | 1,649.00 | 57.60 | 270.00 |  |  | 270.00 |
| 12 | 05053 | 100 | 166.00 | 668.00 | 58.20 | 166.00 |  |  | 166.00 |
| 13 | 01168 |  | 92.00 | 338.00 | 59.80 | 92.00 |  |  | 92.00 |
| 14 | 02329 | 2500 | 2,200.00 | 5,750.00 | 60.00 | 2200.00 |  |  | 2200.00 |
| 15 | 05586 | 100 | 110.00 | 415.00 | 60.80 | 110.00 |  |  | 110.00 |
| 16 | 03729 |  | 235.00 | 1,280.00 | 60.90 | 235.00 |  |  | 235.00 |
| 17 | 06496 | 50 | 86.00 | 365.00 | 61.70 | 86.00 |  |  | 86.00 |
| 18 | 01874 | 160 | 85.00 | 650.00 | 62.30 | 85.00 |  |  | 85.00 |
| 19 | 05554 | 50 | 100.00 | 440.00 | 62.90 | 100.00 |  |  | 100.00 |
| 20 | 02540 | - | 323.00 | 1,826.00 | 65.60 | 323.00 |  |  | 323.00 |
| 21 | 01766 | 630 | 540.00 | 2,100.00 | 65.70 | 540.00 |  |  | 540.00 |
| 22 | 05174 | 50 | 100.00 | 440.00 | 65.80 | 100.00 |  |  | 100.00 |
| 23 | 05197 | 100 | 120.00 | 800.00 | 66.70 | 120.00 |  |  | 120.00 |
| 24 | 06460 | 50 | 117.00 | 437.00 | 67.00 | 117.00 |  |  | 117.00 |
| 25 | 05543 | 50 | 100.00 | 440.00 | 67.30 | 100.00 |  |  | 100.00 |
| 26 | 01802 | 400 | 285.00 | 1,690.00 | 67.40 | 285.00 |  |  | 285.00 |
| 27 | 02392 | 630 | 323.00 | 1,826.00 | 67.40 | 323.00 |  |  | 323.00 |
| 28 | 05715 | 100 | 160.00 | 690.00 | 67.70 | 160.00 |  |  | 160.00 |
| 29 | 06112 | 50 | 100.00 | 450.00 | 70.20 | 100.00 |  |  | 100.00 |
| 30 | 01985 | 1000 | 530.00 | 2,700.00 | 70.50 | 530.00 |  |  | 530.00 |
| 31 | 06444 | 100 | 117.00 | 437.00 | 70.90 | 117.00 |  |  | 117.00 |
| 32 | 05407 | 100 | 100.00 | 440.00 | 72.50 | 100.00 |  |  | 100.00 |
| 33 | 05186 | 250 | 210.00 | 1,090.00 | 73.20 | 210.00 |  |  | 210.00 |
| 34 | 04007 | 400 | 530.00 | 2,700.00 | 73.90 | 530.00 |  |  | 530.00 |
| 35 | 04134 | 250 | 210.00 | 1,090.00 | 77.90 | 210.00 |  |  | 210.00 |
| 36 | 02623 | 250 | 264.00 | 1,205.00 | 78.80 | 264.00 |  |  | 264.00 |
| 37 | 06034 | 100 | 125.00 | 575.00 | 78.80 | 125.00 |  |  | 125.00 |
| 38 | 05405 | 50 | 105.00 | 440.00 | 80.30 | 105.00 |  |  | 105.00 |
| 39 | 06300 | 100 | 177.00 | 728.00 | 80.30 | 177.00 |  |  | 177.00 |
| 40 | 02471 | 630 | 323.00 | 1,833.00 | 81.50 | 323.00 |  |  | 323.00 |
| 41 | 01167 | 250 | 625.00 | 1,845.00 | 83.60 | 625.00 |  |  | 625.00 |
| 42 | 05612 | 100 | 100.00 | 440.00 | 95.90 | 100.00 |  |  | 100.00 |
| 43 | 05501 | 400 | 305.00 | 1,720.00 | 101.50 | 305.00 |  |  | 305.00 |
| 44 | 02185 | 630 | 323.00 | 1,826.00 | 102.70 | 323.00 |  |  | 323.00 |
| 45 | 01757 | 630 | 425.00 | 2,225.00 | 110.00 | 425.00 |  |  | 425.00 |
| 46 | 04130 | 400 | 235.00 | 1,280.00 | 113.00 | 235.00 |  |  | 235.00 |
| 47 | 02201 | 630 | 420.00 | 2,010.00 | 123.50 | 420.00 |  |  | 420.00 |
| 48 | 01142 | 250 | 1,004.00 | 2,750.00 | 142.00 | 1004.00 |  |  | 1004.00 |
| 49 | 04201 | 50 | 350.00 | 1,600.00 | 146.00 | 350.00 |  |  | 350.00 |
| 50 | 02962 |  | 1,100.00 | 4,300.00 | 255.00 | 1100.00 |  |  | 1100.00 |
| 51 | 01837 | 400 | 345.00 | 1,540.00 | 354.00 | 345.00 |  |  | 345.00 |
| 52 | 03700 | 630 | 475.00 | 2,450.00 | 360.00 | 475.00 |  |  | 475.00 |
| 53 | 05379 | 50 | 100.00 | 440.00 | 472.00 | 100.00 |  |  | 100.00 |
| 54 | 02630 | 50 | 151.00 | 522.00 | 519.00 | 151.00 | 151.00 |  | 302.00 |
| 55 | 01754 | 400 | 265.00 | 1,430.00 | 697.00 | 265.00 | 265.00 |  | 530.00 |
| 56 | 02894 | - | 1,100.00 | 4,300.00 | 799.00 | 1100.00 | 1100.00 |  | 2200.00 |
| 57 | 01463 | 1000 | 580.00 | 2,850.00 | 822.00 | 580.00 | 580.00 |  | 1160.00 |
| 58 | 03699 | 630 | 475.00 | 2,450.00 | 926.00 | 475.00 | 475.00 |  | 950.00 |
| 59 | 01092 |  | 125.00 | 493.00 | 2,380.00 | 125.00 | 125.00 |  | 250.00 |
| 60 | 04128 | 250 | 200.00 | 950.00 | 5,001.00 | 200.00 | 200.00 | 200.00 | 600.00 |
| 61 | 02786 | 160 | 431.00 | 1,200.00 | 28,923.00 | 431.00 | 431.00 | 431.00 | 1293.00 |
| 62 | 07000 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  | 472.00 |
| 63 | 07001 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  | 472.00 |
| 64 | 07002 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  | 472.00 |
| 65 | 07003 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  | 472.00 |
| 66 | 07004 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  | 472.00 |
| 67 | 07005 | 630 | 472.00 | 2,252.00 | 500-2,000 | 472.00 | 472.00 |  | 944.00 |
| 68 | 07006 | 630 | 472.00 | 2,252.00 | 2,000-20,000 | 472.00 | 472.00 | 472.00 | 1416.00 |
|  | **Total:** | | **23,550** | **102,852** |  | **21,354** | **4,146** | **1,103** | **26,603** |

**Annex 4: Retrofilling cycles to up to 10 ppm**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ord. no.** | **ID** | **Capacity kVA** | **Oil (kg) per unit** | **Total (kg) per unit** | **PCB**  **(ppm)** | **Retrofilling cycle** | | | | **Total** |
| **I** | **II** | **III** | **IV** |
| 1 | 06508 | 100 | 110.00 | 415.00 | 50.20 | 110.00 |  |  |  | 110.00 |
| 2 | 01759 | 630 | 540.00 | 2,100.00 | 50.40 | 540.00 |  |  |  | 540.00 |
| 3 | 01760 | 630 | 540.00 | 2,100.00 | 51.70 | 540.00 |  |  |  | 540.00 |
| 4 | 05402 | 50 | 100.00 | 440.00 | 51.90 | 100.00 |  |  |  | 100.00 |
| 5 | 05154 | 50 | 100.00 | 440.00 | 52.00 | 100.00 |  |  |  | 100.00 |
| 6 | 03393 | 400 | 300.00 | 1,540.00 | 52.30 | 300.00 |  |  |  | 300.00 |
| 7 | 02375 | 630 | 323.00 | 1,826.00 | 52.40 | 323.00 |  |  |  | 323.00 |
| 8 | 03428 | 50 | 86.00 | 365.00 | 53.90 | 86.00 |  |  |  | 86.00 |
| 9 | 03020 | 400 | 270.00 | 1,649.00 | 56.70 | 270.00 |  |  |  | 270.00 |
| 10 | 01853 | 630 | 540.00 | 2,100.00 | 57.50 | 540.00 |  |  |  | 540.00 |
| 11 | 03071 | - | 270.00 | 1,649.00 | 57.60 | 270.00 |  |  |  | 270.00 |
| 12 | 05053 | 100 | 166.00 | 668.00 | 58.20 | 166.00 |  |  |  | 166.00 |
| 13 | 01168 |  | 92.00 | 338.00 | 59.80 | 92.00 |  |  |  | 92.00 |
| 14 | 02329 | 2500 | 2,200.00 | 5,750.00 | 60.00 | 2200.00 |  |  |  | 2200.00 |
| 15 | 05586 | 100 | 110.00 | 415.00 | 60.80 | 110.00 |  |  |  | 110.00 |
| 16 | 03729 |  | 235.00 | 1,280.00 | 60.90 | 235.00 |  |  |  | 235.00 |
| 17 | 06496 | 50 | 86.00 | 365.00 | 61.70 | 86.00 |  |  |  | 86.00 |
| 18 | 01874 | 160 | 85.00 | 650.00 | 62.30 | 85.00 |  |  |  | 85.00 |
| 19 | 05554 | 50 | 100.00 | 440.00 | 62.90 | 100.00 |  |  |  | 100.00 |
| 20 | 02540 | - | 323.00 | 1,826.00 | 65.60 | 323.00 |  |  |  | 323.00 |
| 21 | 01766 | 630 | 540.00 | 2,100.00 | 65.70 | 540.00 |  |  |  | 540.00 |
| 22 | 05174 | 50 | 100.00 | 440.00 | 65.80 | 100.00 |  |  |  | 100.00 |
| 23 | 05197 | 100 | 120.00 | 800.00 | 66.70 | 120.00 |  |  |  | 120.00 |
| 24 | 06460 | 50 | 117.00 | 437.00 | 67.00 | 117.00 |  |  |  | 117.00 |
| 25 | 05543 | 50 | 100.00 | 440.00 | 67.30 | 100.00 |  |  |  | 100.00 |
| 26 | 01802 | 400 | 285.00 | 1,690.00 | 67.40 | 285.00 |  |  |  | 285.00 |
| 27 | 02392 | 630 | 323.00 | 1,826.00 | 67.40 | 323.00 |  |  |  | 323.00 |
| 28 | 05715 | 100 | 160.00 | 690.00 | 67.70 | 160.00 |  |  |  | 160.00 |
| 29 | 06112 | 50 | 100.00 | 450.00 | 70.20 | 100.00 |  |  |  | 100.00 |
| 30 | 01985 | 1000 | 530.00 | 2,700.00 | 70.50 | 530.00 |  |  |  | 530.00 |
| 31 | 06444 | 100 | 117.00 | 437.00 | 70.90 | 117.00 |  |  |  | 117.00 |
| 32 | 05407 | 100 | 100.00 | 440.00 | 72.50 | 100.00 |  |  |  | 100.00 |
| 33 | 05186 | 250 | 210.00 | 1,090.00 | 73.20 | 210.00 |  |  |  | 210.00 |
| 34 | 04007 | 400 | 530.00 | 2,700.00 | 73.90 | 530.00 |  |  |  | 530.00 |
| 35 | 04134 | 250 | 210.00 | 1,090.00 | 77.90 | 210.00 |  |  |  | 210.00 |
| 36 | 02623 | 250 | 264.00 | 1,205.00 | 78.80 | 264.00 |  |  |  | 264.00 |
| 37 | 06034 | 100 | 125.00 | 575.00 | 78.80 | 125.00 |  |  |  | 125.00 |
| 38 | 05405 | 50 | 105.00 | 440.00 | 80.30 | 105.00 |  |  |  | 105.00 |
| 39 | 06300 | 100 | 177.00 | 728.00 | 80.30 | 177.00 |  |  |  | 177.00 |
| 40 | 02471 | 630 | 323.00 | 1,833.00 | 81.50 | 323.00 |  |  |  | 323.00 |
| 41 | 01167 | 250 | 625.00 | 1,845.00 | 83.60 | 625.00 |  |  |  | 625.00 |
| 42 | 05612 | 100 | 100.00 | 440.00 | 95.90 | 100.00 |  |  |  | 100.00 |
| 43 | 05501 | 400 | 305.00 | 1,720.00 | 101.50 | 305.00 | 305.00 |  |  | 610.00 |
| 44 | 02185 | 630 | 323.00 | 1,826.00 | 102.70 | 323.00 | 323.00 |  |  | 646.00 |
| 45 | 01757 | 630 | 425.00 | 2,225.00 | 110.00 | 425.00 | 425.00 |  |  | 850.00 |
| 46 | 04130 | 400 | 235.00 | 1,280.00 | 113.00 | 235.00 | 235.00 |  |  | 470.00 |
| 47 | 02201 | 630 | 420.00 | 2,010.00 | 123.50 | 420.00 | 420.00 |  |  | 840.00 |
| 48 | 01142 | 250 | 1,004.00 | 2,750.00 | 142.00 | 1004.00 | 1004.00 |  |  | 2008.00 |
| 49 | 04201 | 50 | 350.00 | 1,600.00 | 146.00 | 350.00 | 350.00 |  |  | 700.00 |
| 50 | 02962 |  | 1,100.00 | 4,300.00 | 255.00 | 1100.00 | 1100.00 |  |  | 2200.00 |
| 51 | 01837 | 400 | 345.00 | 1,540.00 | 354.00 | 345.00 | 345.00 |  |  | 690.00 |
| 52 | 03700 | 630 | 475.00 | 2,450.00 | 360.00 | 475.00 | 475.00 |  |  | 950.00 |
| 53 | 05379 | 50 | 100.00 | 440.00 | 472.00 | 100.00 | 100.00 |  |  | 200.00 |
| 54 | 02630 | 50 | 151.00 | 522.00 | 519.00 | 151.00 | 151.00 |  |  | 302.00 |
| 55 | 01754 | 400 | 265.00 | 1,430.00 | 697.00 | 265.00 | 265.00 |  |  | 530.00 |
| 56 | 02894 | - | 1,100.00 | 4,300.00 | 799.00 | 1100.00 | 1100.00 |  |  | 2200.00 |
| 57 | 01463 | 1000 | 580.00 | 2,850.00 | 822.00 | 580.00 | 580.00 |  |  | 1160.00 |
| 58 | 03699 | 630 | 475.00 | 2,450.00 | 926.00 | 475.00 | 475.00 |  |  | 950.00 |
| 59 | 01092 |  | 125.00 | 493.00 | 2,380.00 | 125.00 | 125.00 |  |  | 250.00 |
| 60 | 04128 | 250 | 200.00 | 950.00 | 5,001.00 | 200.00 | 200.00 | 200.00 |  | 600.00 |
| 61 | 02786 | 160 | 431.00 | 1,200.00 | 28,923.00 | 431.00 | 431.00 | 431.00 | 431.00 | 1724.00 |
| 62 | 07000 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  |  | 472.00 |
| 63 | 07001 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  |  | 472.00 |
| 64 | 07002 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  |  | 472.00 |
| 65 | 07003 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  |  | 472.00 |
| 66 | 07004 | 630 | 472.00 | 2,252.00 | <500 | 472.00 |  |  |  | 472.00 |
| 67 | 07005 | 630 | 472.00 | 2,252.00 | 500-2,000 | 472.00 | 472.00 |  |  | 944.00 |
| 68 | 07006 | 630 | 472.00 | 2,252.00 | 2,000-20,000 | 472.00 | 472.00 | 472.00 |  | 1416.00 |
|  | **Total:** | | **23,550** | **102,852** |  | **21,354** | **7,874** | **1,103** | **431** | **30,762** |

**Annex 5: Calculations on the extension life-time of the treated transformers**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ord. no.** | **ID** | **Year of production** | **Ext. Life\*\*** | **Capacity kVA** | **Total (kg) per unit** | **Oil (kg) per unit** | **Discount rate** | **Price € new transformer** | **Extension benefit** |
| 1 | 06300 | 1960 | 7 | 100 | 177.00 | 728.00 | 1.0617 | 2,500 | 856 |
| 5 | 02630 | 1969 | 7 | 50 | 151.00 | 522.00 | 1.0617 | 2,000 | 685 |
| 6 | 05154 | 1969 | 7 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 685 |
| 7 | 02623 | 1970 | 7 | 250 | 264.00 | 1,205.00 | 1.0617 | 4,500 | 1,541 |
| 8 | 03393 | 1971 | 7 | 400 | 300.00 | 1,540.00 | 1.0617 | 6,200 | 2,123 |
| 9 | 01759 | 1972 | 7 | 630 | 540.00 | 2,100.00 | 1.0617 | 8,000 | 2,739 |
| 10 | 01853 | 1972 | 7 | 630 | 540.00 | 2,100.00 | 1.0617 | 8,000 | 2,739 |
| 11 | 05053 | 1972 | 7 | 100 | 166.00 | 668.00 | 1.0617 | 2,500 | 856 |
| 12 | 01760 | 1974 | 7 | 630 | 540.00 | 2,100.00 | 1.0617 | 8,000 | 2,739 |
| 13 | 01766 | 1974 | 7 | 630 | 540.00 | 2,100.00 | 1.0617 | 8,000 | 2,739 |
| 14 | 02375 | 1974 | 7 | 630 | 323.00 | 1,826.00 | 1.0617 | 8,000 | 2,739 |
| 15 | 02392 | 1974 | 7 | 630 | 323.00 | 1,826.00 | 1.0617 | 8,000 | 2,739 |
| 16 | 05379 | 1974 | 7 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 685 |
| 17 | 05612 | 1974 | 7 | 100 | 100.00 | 440.00 | 1.0617 | 2,500 | 856 |
| 18 | 05402 | 1976 | 7 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 685 |
| 19 | 06508 | 1976 | 7 | 100 | 110.00 | 415.00 | 1.0617 | 2,500 | 856 |
| 20 | 05405 | 1977 | 7 | 50 | 105.00 | 440.00 | 1.0617 | 2,000 | 685 |
| 21 | 06496 | 1977 | 7 | 50 | 86.00 | 365.00 | 1.0617 | 2,000 | 685 |
| 22 | 03428 | 1977 | 7 | 50 | 86.00 | 365.00 | 1.0617 | 2,000 | 685 |
| 23 | 05501 | 1978 | 7 | 400 | 305.00 | 1,720.00 | 1.0617 | 6,200 | 2,123 |
| 24 | 06444 | 1978 | 7 | 100 | 117.00 | 437.00 | 1.0617 | 2,500 | 856 |
| 25 | 04007 | 1978 | 7 | 400 | 530.00 | 2,700.00 | 1.0617 | 6,200 | 2,123 |
| 26 | 01757 | 1979 | 7 | 630 | 425.00 | 2,225.00 | 1.0617 | 8,000 | 2,739 |
| 27 | 01802 | 1979 | 7 | 400 | 285.00 | 1,690.00 | 1.0617 | 6,200 | 2,123 |
| 28 | 02786 | 1979 | 7 | 160 | 431.00 | 1,200.00 | 1.0617 | 3,500 | 1,198 |
| 29 | 05197 | 1979 | 7 | 100 | 120.00 | 800.00 | 1.0617 | 2,500 | 856 |
| 30 | 01754 | 1980 | 7 | 400 | 265.00 | 1,430.00 | 1.0617 | 6,200 | 2,123 |
| 31 | 05715 | 1980 | 7 | 100 | 160.00 | 690.00 | 1.0617 | 2,500 | 856 |
| 32 | 06112 | 1980 | 7 | 50 | 100.00 | 450.00 | 1.0617 | 2,000 | 685 |
| 33 | 06460 | 1980 | 7 | 50 | 117.00 | 437.00 | 1.0617 | 2,000 | 685 |
| 34 | 03020 | 1981 | 7 | 400 | 270.00 | 1,649.00 | 1.0617 | 6,200 | 2,123 |
| 35 | 04130 | 1981 | 7 | 400 | 235.00 | 1,280.00 | 1.0617 | 6,200 | 2,123 |
| 36 | 01874 | 1982 | 7 | 160 | 85.00 | 650.00 | 1.0617 | 3,500 | 1,198 |
| 37 | 03699 | 1982 | 7 | 630 | 475.00 | 2,450.00 | 1.0617 | 8,000 | 2,739 |
| 38 | 03700 | 1982 | 7 | 630 | 475.00 | 2,450.00 | 1.0617 | 8,000 | 2,739 |
| 39 | 06034 | 1983 | 7 | 100 | 125.00 | 575.00 | 1.0617 | 2,500 | 856 |
| 40 | 05543 | 1984 | 7 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 685 |
| 41 | 04128 | 1984 | 7 | 250 | 200.00 | 950.00 | 1.0617 | 4,500 | 1,541 |
| 42 | 05174 | 1985 | 7 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 685 |
| 43 | 04134 | 1985 | 7 | 250 | 210.00 | 1,090.00 | 1.0617 | 4,500 | 1,541 |
| 44 | 05186 | 1988 | 7 | 250 | 210.00 | 1,090.00 | 1.0617 | 4,500 | 1,541 |
| 45 | 02185 | 2000 | 7 | 630 | 323.00 | 1,826.00 | 1.0617 | 8,000 | 2,739 |
| 46 | 02471 | 2000 | 7 | 630 | 323.00 | 1,833.00 | 1.0617 | 8,000 | 2,739 |
| 47 | 02201 | 2003 | 7 | 630 | 420.00 | 2,010.00 | 1.0617 | 8,000 | 2,739 |
| 48 | 01985 | 2013 | 7 | 1000 | 530.00 | 2,700.00 | 1.0617 | 9,500 | 3,252 |
| 49 | 01463 | 2017 | 7 | 1000 | 580.00 | 2,850.00 | 1.0617 | 9,500 | 3,252 |
| 52 | 02329 | 1985\* | 7 | 2500 | 2,200.00 | 5,750.00 | 1.0617 | 20,000 | 6,847 |
| 53 | 02540 | 1985\* | 7 | 630 | 323.00 | 1,826.00 | 1.0617 | 8,000 | 2,739 |
| 54 | 02894 | 1985\* | 7 | 1000 | 1,100.00 | 4,300.00 | 1.0617 | 9,500 | 3,252 |
| 55 | 02962 | 1985\* | 7 | 1000 | 1,100.00 | 4,300.00 | 1.0617 | 9,500 | 3,252 |
| 56 | 03071 | 1985\* | 7 | 400 | 270.00 | 1,649.00 | 1.0617 | 6,200 | 2,123 |
| 57 | 01837 | 1985\* | 7 | 400 | 345.00 | 1,540.00 | 1.0617 | 6,200 | 2,123 |
| 58 | 05407 | 1985\* | 7 | 100 | 100.00 | 440.00 | 1.0617 | 2,500 | 856 |
| 59 | 05554 | 1985\* | 7 | 50 | 100.00 | 440.00 | 1.0617 | 2,000 | 685 |
| 60 | 05586 | 1985\* | 7 | 100 | 110.00 | 415.00 | 1.0617 | 2,500 | 856 |
| 61 | 03729 | 1985\* | 7 | 250 | 235.00 | 1,280.00 | 1.0617 | 4,500 | 1,541 |
| 62 |  | 1985\* | 7 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,739 |
| 63 |  | 1985\* | 7 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,739 |
| 64 |  | 1985\* | 7 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,739 |
| 65 |  | 1985\* | 7 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,739 |
| 66 |  | 1985\* | 7 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,739 |
| 67 |  | 1985\* | 7 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,739 |
| 68 |  | 1985\* | 7 | 630 | 472.00 | 2,252.00 | 1.0617 | 8,000 | 2,739 |
|  | **Total:** | | | | **23,550** | **102,852** |  |  | **120,614** |

\* Transformers with unknown year of production and assumed year of production of 1985

\*\* Period of 7 years is used as a prolongation of the useful life time of the transformers after the treatment

**Annex 6: Calculation of the replacement costs (KAP transformers)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ord.**  **no.** | **ID** | **Year of production** | **Exp.**  **Life** | **Capacity kVA** | **Total (kg) per unit** | **Oil (kg) per unit** | **Discount rate** | **Price € new transformer** | **Replacement costs €** |
| 1 | 01291 | 1975 | 5 | 1250 | 4,300.00 | 1,356.00 | 1.0617 | 11,500 | 2,975 |
| 2 | 01299 | 1986 | 5 | 1250 | 3,400.00 | 1,100.00 | 1.0617 | 11,500 | 3,471 |
| 3 | 01302 | 1984 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 4 | 01344 | - | 5 | 1000 | 2,950.00 | 1,000.00 | 1.0617 | 9,500 | 2,458 |
| 5 | 01304 | 1986 | 5 | 1000 | 4,300.00 | 1,100.00 | 1.0617 | 9,500 | 2,458 |
| 6 | 01061 | - | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 7 | 01294 | - | 5 | 1250 | 3,790.00 | 720.00 | 1.0617 | 11,500 | 2,975 |
| 8 | 01292 | 1975 | 5 | 1250 | 4,300.00 | 1,350.00 | 1.0617 | 11,500 | 2,975 |
| 9 | 01334 | 1970 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 10 | 01339 | 1978 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 11 | 01031 | 1970 | 5 | 630 | 2,400.00 | 700.00 | 1.0617 | 8,000 | 2,070 |
| 12 | 01327 | - | 5 | 630 | 2,335.00 | 466.00 | 1.0617 | 8,000 | 2,070 |
| 13 | 01060 | 1970 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 14 | 01059 | 1978 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 15 | 01346 | 1978 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 16 | 01298 | - | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 17 | 01340 | 1974 | 5 | 1000 | 3,100.00 | 650.00 | 1.0617 | 9,500 | 2,458 |
| 18 | 01037 | - | 5 | 1250 | 4,300.00 | 1,280.00 | 1.0617 | 11,500 | 2,975 |
| 19 | 01036 | 1979 | 5 | 1000 | 2,750.00 | 1,040.00 | 1.0617 | 9,500 | 2,458 |
| 20 | 01301 | 1970 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 21 | 01326 | 1979 | 5 | 1000 | 2,750.00 | 1,004.00 | 1.0617 | 9,500 | 2,458 |
| 22 | 01039 | 1970 | 5 | 630 | 2,400.00 | 698.00 | 1.0617 | 8,000 | 2,070 |
| 23 | 01040 | 1970 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 24 | 01034 | 1978 | 5 | 630 | 2,400.00 | 698.00 | 1.0617 | 8,000 | 2,070 |
| 25 | 01032 | 1970 | 5 | 630 | 2,400.00 | 69.00 | 1.0617 | 8,000 | 2,070 |
| 26 | 01046 | - | 5 | 250 | 1,400.00 | 275.00 | 1.0617 | 4,500 | 1,164 |
| 27 | 01348 | 1970 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,975 |
| 28 | 01038 | 1970 | 5 | 630 | 2,400.00 | 698.00 | 1.0617 | 8,000 | 2,070 |
| 29 | 01043 | - | 5 | 400 | 1,400.00 | 275.00 | 1.0617 | 6,200 | 1,604 |
| 30 | 01347 | 1970 | 5 | 1250 | 4,300.00 | 1,100.00 | 1.0617 | 11,500 | 2,458 |
|  | **Total:** | | | | **104,675.00** | **27,679.00** |  |  | **78,029** |

**Annex 7: Retrofilling cycles to up to 50 ppm (KAP transformers)**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ord.**  **no.** | **ID** | **Capacity kVA** | **Total (kg) per unit** | **Oil (kg) per unit** | **PCB**  **(ppm)** | **Retrofilling cycle** | | | | | **Total** |
| **I** | **II** | **III** | **IV** | **V** |
| 1 | 01291 |  | 4,300.00 | 1,356.00 | 102.00 | 1,356.00 |  |  |  |  | 1,356.00 |
| 2 | 01299 |  | 3,400.00 | 1,100.00 | 273.00 | 1,100.00 |  |  |  |  | 1,100.00 |
| 3 | 01302 |  | 4,300.00 | 1,100.00 | 273.00 | 1,100.00 |  |  |  |  | 1,100.00 |
| 4 | 01344 |  | 2,950.00 | 1,000.00 | 512.00 | 1,000.00 | 1,000.00 |  |  |  | 2,000.00 |
| 5 | 01304 |  | 4,300.00 | 1,100.00 | 608.00 | 1,100.00 | 1,100.00 |  |  |  | 2,200.00 |
| 6 | 01061 |  | 4,300.00 | 1,100.00 | 1599.00 | 1,100.00 | 1,100.00 |  |  |  | 2,200.00 |
| 7 | 01294 |  | 3,790.00 | 720.00 | 1665.00 | 720.00 | 720.00 |  |  |  | 1,440.00 |
| 8 | 01292 |  | 4,300.00 | 1,350.00 | 3394.00 | 1,350.00 | 1,350.00 |  |  |  | 2,700.00 |
| 9 | 01334 |  | 4,300.00 | 1,100.00 | 4057.00 | 1,100.00 | 1,100.00 |  |  |  | 2,200.00 |
| 10 | 01339 |  | 4,300.00 | 1,100.00 | 6100.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 11 | 01031 | 630 | 2,400.00 | 700.00 | 6500.00 | 700.00 | 700.00 | 700.00 |  |  | 2,100.00 |
| 12 | 01327 | 630 | 2,335.00 | 466.00 | 7946.00 | 466.00 | 466.00 | 466.00 |  |  | 1,398.00 |
| 13 | 01060 |  | 4,300.00 | 1,100.00 | 9678.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 14 | 01059 |  | 4,300.00 | 1,100.00 | 10582.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 15 | 01346 |  | 4,300.00 | 1,100.00 | 11874.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 16 | 01298 |  | 4,300.00 | 1,100.00 | 12042.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 17 | 01340 | 1000 | 3,100.00 | 650.00 | 14000.00 | 650.00 | 650.00 | 650.00 |  |  | 1,950.00 |
| 18 | 01037 |  | 4,300.00 | 1,280.00 | 21000.00 | 1,280.00 | 1,280.00 | 1,280.00 |  |  | 3,840.00 |
| 19 | 01036 |  | 2,750.00 | 1,040.00 | 36567.00 | 1,040.00 | 1,040.00 | 1,040.00 |  |  | 3,120.00 |
| 20 | 01301 |  | 4,300.00 | 1,100.00 | 95000.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 |  | 4,400.00 |
| 21 | 01326 |  | 2,750.00 | 1,004.00 | 965539.00 | 1,004.00 | 1,004.00 | 1,004.00 | 1,004.00 | 1,004.00 | 5,020.00 |
| 22 | 01039 | 630 | 2,400.00 | 698.00 | 969989.00 | 698.00 | 698.00 | 698.00 | 698.00 | 698.00 | 3,490.00 |
| 23 | 01040 |  | 4,300.00 | 1,100.00 | 974515.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 5,500.00 |
| 24 | 01034 | 630 | 2,400.00 | 698.00 | 975606.00 | 698.00 | 698.00 | 698.00 | 698.00 | 698.00 | 3,490.00 |
| 25 | 01032 | 630 | 2,400.00 | 69.00 | 979334.00 | 69.00 | 69.00 | 69.00 | 69.00 | 69.00 | 345.00 |
| 26 | 01046 | 250 | 1,400.00 | 275.00 | 983459.00 | 275.00 | 275.00 | 275.00 | 275.00 | 275.00 | 1,375.00 |
| 27 | 01348 |  | 4,300.00 | 1,100.00 | 984160.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 5,500.00 |
| 28 | 01038 | 630 | 2,400.00 | 698.00 | 985300.00 | 698.00 | 698.00 | 698.00 | 698.00 | 698.00 | 3,490.00 |
| 29 | 01043 | 400 | 1,400.00 | 275.00 | 986539.00 | 275.00 | 275.00 | 275.00 | 275.00 | 275.00 | 1,375.00 |
| 30 | 01347 |  | 4,300.00 | 1,100.00 | 988589.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 5,500.00 |
|  | **Total:** | | **104,675.00** | **27,679.00** |  | **27,679.00** | **24,123.00** | **17,753.00** | **8,117.00** | **7,017.00** | **84,689.00** |
|  |  |  |  |  |  |  |  |  |  |  |  |

**Annex 8: Retrofilling cycles to up to 10 ppm (KAP transformers)**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ord.**  **no.** | **ID** | **Capacity kVA** | **Total (kg) per unit** | **Oil (kg) per unit** | **PCB**  **(ppm)** | **Retrofilling cycle** | | | | | **Total** |
| **I** | **II** | **III** | **IV** | **V** |
| 1 | 01291 |  | 4,300.00 | 1,356.00 | 102.00 | 1,356.00 | 1,356.00 |  |  |  | 2,712.00 |
| 2 | 01299 |  | 3,400.00 | 1,100.00 | 273.00 | 1,100.00 | 1,100.00 |  |  |  | 2,200.00 |
| 3 | 01302 |  | 4,300.00 | 1,100.00 | 273.00 | 1,100.00 | 1,100.00 |  |  |  | 2,200.00 |
| 4 | 01344 |  | 2,950.00 | 1,000.00 | 512.00 | 1,000.00 | 1,000.00 |  |  |  | 2,000.00 |
| 5 | 01304 |  | 4,300.00 | 1,100.00 | 608.00 | 1,100.00 | 1,100.00 |  |  |  | 2,200.00 |
| 6 | 01061 |  | 4,300.00 | 1,100.00 | 1599.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 7 | 01294 |  | 3,790.00 | 720.00 | 1665.00 | 720.00 | 720.00 | 720.00 |  |  | 2,160.00 |
| 8 | 01292 |  | 4,300.00 | 1,350.00 | 3394.00 | 1,350.00 | 1,350.00 | 1,350.00 |  |  | 4,050.00 |
| 9 | 01334 |  | 4,300.00 | 1,100.00 | 4057.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 10 | 01339 |  | 4,300.00 | 1,100.00 | 6100.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 11 | 01031 | 630 | 2,400.00 | 700.00 | 6500.00 | 700.00 | 700.00 | 700.00 |  |  | 2,100.00 |
| 12 | 01327 | 630 | 2,335.00 | 466.00 | 7946.00 | 466.00 | 466.00 | 466.00 |  |  | 1,398.00 |
| 13 | 01060 |  | 4,300.00 | 1,100.00 | 9678.00 | 1,100.00 | 1,100.00 | 1,100.00 |  |  | 3,300.00 |
| 14 | 01059 |  | 4,300.00 | 1,100.00 | 10582.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 |  | 4,400.00 |
| 15 | 01346 |  | 4,300.00 | 1,100.00 | 11874.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 |  | 4,400.00 |
| 16 | 01298 |  | 4,300.00 | 1,100.00 | 12042.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 |  | 4,400.00 |
| 17 | 01340 | 1000 | 3,100.00 | 650.00 | 14000.00 | 650.00 | 650.00 | 650.00 | 650.00 |  | 2,600.00 |
| 18 | 01037 |  | 4,300.00 | 1,280.00 | 21000.00 | 1,280.00 | 1,280.00 | 1,280.00 | 1,280.00 |  | 5,120.00 |
| 19 | 01036 |  | 2,750.00 | 1,040.00 | 36567.00 | 1,040.00 | 1,040.00 | 1,040.00 | 1,040.00 |  | 4,160.00 |
| 20 | 01301 |  | 4,300.00 | 1,100.00 | 95000.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 |  | 4,400.00 |
| 21 | 01326 |  | 2,750.00 | 1,004.00 | 965539.00 | 1,004.00 | 1,004.00 | 1,004.00 | 1,004.00 | 1,004.00 | 5,020.00 |
| 22 | 01039 | 630 | 2,400.00 | 698.00 | 969989.00 | 698.00 | 698.00 | 698.00 | 698.00 | 698.00 | 3,490.00 |
| 23 | 01040 |  | 4,300.00 | 1,100.00 | 974515.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 5,500.00 |
| 24 | 01034 | 630 | 2,400.00 | 698.00 | 975606.00 | 698.00 | 698.00 | 698.00 | 698.00 | 698.00 | 3,490.00 |
| 25 | 01032 | 630 | 2,400.00 | 69.00 | 979334.00 | 69.00 | 69.00 | 69.00 | 69.00 | 69.00 | 345.00 |
| 26 | 01046 | 250 | 1,400.00 | 275.00 | 983459.00 | 275.00 | 275.00 | 275.00 | 275.00 | 275.00 | 1,375.00 |
| 27 | 01348 |  | 4,300.00 | 1,100.00 | 984160.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 5,500.00 |
| 28 | 01038 | 630 | 2,400.00 | 698.00 | 985300.00 | 698.00 | 698.00 | 698.00 | 698.00 | 698.00 | 3,490.00 |
| 29 | 01043 | 400 | 1,400.00 | 275.00 | 986539.00 | 275.00 | 275.00 | 275.00 | 275.00 | 275.00 | 1,375.00 |
| 30 | 01347 |  | 4,300.00 | 1,100.00 | 988589.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 1,100.00 | 5,500.00 |
|  | **Total:** | | **104,675.00** | **27,679.00** |  | **27,679.00** | **27,679.00** | **22,023.00** | **14,387.00** | **7,017.00** | **98,785.00** |