



## Review article

## Economic feasibility proposal for treatment and/or disposal technologies of dielectric oils contaminated with PCB

C. González<sup>a,\*</sup>, D. Bolaños-Guerrón<sup>a,b</sup><sup>a</sup> Departamento de Ciencias de la Tierra y la construcción, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador<sup>b</sup> Centro de Nanociencia y nanotecnología CENCINAT, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador

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## ABSTRACT

Ecuador is a signatory of the Stockholm Convention on chemical substances and hazardous waste and is responsible for complying with the guidelines for the environmentally adequate disposal of Polychlorinated Biphenyls (PCBs) in the country until 2025. The global management of PCBs begins with the sampling of transformers, analysis of dielectric oil, characterization and final disposal of transformers, oil and PCB material belonging to the electricity sector and private owners. The information on the characterization of PCBs is recorded and stored in a computer system called the National PCB Inventory and Monitoring System (SNIS-PCB), in which, the information of 216,632 transformers must be recorded for the present investigation. In the past 2018, the system registered 90,346 transformers, equivalent to 40% of the inventory, 3,494 of them were contaminated and are owned by electricity companies, and it was estimated that there are 1,063 contaminated transformers from private owners. The objective of the research is to analyze the economic and technical feasibility of the technologies available and allowed in the national regulations for the final disposal of these hazardous wastes. According to the technical characteristics of the technologies, logistical limitations and quantity of PCBs in the country, it has been determined that Dichlorination is a technological option that can be used for the treatment of PCBs, also offering the opportunity of decontamination, reuse of the material, and it is friendly with the environment.

## 1. Introduction

Ecuador ratified the Stockholm Convention on chemical substances and hazardous waste in June 2004 and presented its National Implementation Plan (PNI) in 2006. One of the objectives is to eliminate all PCBs in Ecuador by 2025 and establish temporary storage sites for transformers and contaminated dielectric oils (UNDP, 2013). PCBs are persistent organic compounds known internationally by their acronym in English POPs (Persistent Organic Pollutants). They were synthesized for the first time in the middle of the 19th century on a laboratory scale, and are manufactured commercially since 1930, using them in various industrial applications as insulating material and heat exchange fluids for transformers and condensers. As they are oil-soluble, bioaccumulatable, biomagnifier, and persistent in the environment, PCBs are a threat to human health and the environment (Ministry of the Environment, 2017).

On human health, they cause alterations in the endocrine system, while on animals directly affect reproduction. Their effects are evidenced at very low doses, generally well below the legally established exposure

limits (Crespo, Olano, & Hernández, Status of PCB decontamination and destruction technologies without incineration, 2010), for example, a person may be exposed to inhalation below the limit of  $1 \text{ mg m}^{-3}$ , but this is a time weighted value, and means the concentration for a normal working day in an average of 40 weekly working hours in closed environments, as established by the NIOSH standard (The National Institute for Occupational Safety and Health), it is estimated that humans can be exposed to levels of up to  $0.0001 \text{ ugL}^{-1}$ , in cold fresh water according to the TULSMA (Unified Text of Secondary Legislation of the Ministry of the Environment) and in food in general, the population can ingest levels between 0.2-3 ppm (Parts per million) (Ministry of the Environment, 2015).

Based on this problem organizations around the world, knowing how dangerous these substances are, banned their production, and most countries stopped it in 1983, it is so Ecuador adopted the Stockholm Convention on Persistent Organic Pollutants, and became effective on May 17th, 2004. The mentioned agreement is a global treaty that protects human health and the environment from (POPs) and requires the parties

\* Corresponding author.

E-mail address: [connygon@hotmail.com](mailto:connygon@hotmail.com) (C. González).

to take measures to eliminate or reduce the emission of POPs into the environment (Ministry of the Environment, 2017), since 2016 Ecuador has a specific regulation for PCBs, mainly focused on the electricity sector, which has an inventory of around 216,632 transformers possibly contaminated with PCB. In this context, the objective of this research seeks to analyze the economic feasibility of technologies for the treatment and/or elimination of oil contaminated with PCB (>50 ppm) in Ecuador.

## 2. Methodology

For the development of the methodology, the information and data of the inventory declared by the Electricity Companies were analyzed at national level, along with environmental regulations, available technologies and their technical characteristics provided by the PCB Project of the United Nations Development Program (UNDP) and Ministry of the Environment and Water of Ecuador, as well as the costs of the companies that carry out the environmental management of these hazardous wastes among other costs that may incur in the management, such as temporary storage, and transportation. The study area was developed in the city of Quito, a bibliographic and technical-economic analysis of the existing technologies and allowed by national environmental legislation for the final treatment of PCBs was carried out, as a first step, it was necessary to know the inventory in terms of quantities (weight and volume) of transformers, and oils contaminated with PCBs as shown below.

### 2.1. Inventory

To know the quantity and weight of transformers contaminated with PCB, the data declared in the SNIS-PCB inventory was used, taking into account that the information platform only collects information on transformers manufactured up to 2011, considering that, for 2012, adding PCBs to dielectric oil was banned worldwide. The data were collected from 10 electricity generation companies and 20 electricity distribution companies, which must complete the inventory of 216,632 transformers until December 31st, 2020 based on the guidelines of Ministerial Agreement 146 (AM 146). The Inventory started in May 2016, however, for the date of this investigation, in 2018, the number of characterized transformers was 90,346 equivalents to the 41.07%, of this total 3,494 transformers contaminated with PCBs were identified, with a total weight of 436.4 tons. The registered weight of each transformer in the SNIS-PCB includes the weight of oil. AM 146 establishes that, in the case of contaminated transformers, the extraction of the oil will not be authorized until its final disposal, therefore the weight presented is made up of the weight of the transformer plus the weight of the oil, these values have been compiled from the information declared by the electricity companies in the SNIS-PCB. For the research, oil and transformer values will be obtained, in order to obtain an economic reference for the management of each one.

In accordance with the above, an average volume of 80 L of dielectric oil per equipment is considered, based on the information obtained from the SNIS-PCB system, it was not considered to use the density of the dielectric oil to determine its volume, due to this data is not available in all the transformers declared in the SNIS-PCB; also, the density of each transformers related to the year of manufacture, maintenance carried out during its useful life, etc.

### 2.2. Treatment and disposal technologies for PCB

When defining the technology, several criteria is considered, such as public acceptance, risks, environmental impact, applicability of the method, approved technologies, minimum achievable concentration, required clean-up time, reliability, maintenance, cost of post-treatment, destruction efficiency and emissions of gases such as dioxins and furans into the environment (Ministry of the Environment, 2016). PCBs are halogenated organic compounds, and present a great molecular

arrangement problem, due to the highly stable nature of the carbon-halogen bonds. Many halogenated organic compounds are not only resistant to biodegradation, but cannot be degraded in a practical way by well-known methods, these processes involve the use of expensive reagents, inert atmospheres, temperature control, complex devices and high energy consumption (FODECYT Project, 2011).

For this research, technologies allowed by Ecuadorian legislation were analyzed, these are briefly described below:

- The autoclave is a decontamination treatment that extracts the PCB from the contaminated material.
- Dechlorination this method consists of a reaction between the dielectric fluid and metallic sodium, lithium or potassium. The metallic reagent reacts with the chlorine atoms of PCBs generating metallic chloride and other non-halogenated residual products.
- Decomposition by basic catalysis, liquid and solid waste are treated in the presence of a high-boiling oil, soda and a catalyst. Reactive hydrogen atoms are generated in the process that attack organochlorine residues. The final products are formed by a carbonaceous residue and achieving sodium salts.
- Supercritical water oxidation in this treatment, the water above its critical point is transforms into a single reaction medium where hydrocarbons and molecular oxygen have infinite solubility. The main oxidation products are acetic acid, alcohols, carbon oxides and organic residues.
- Incineration of hazardous waste is the most used technology for the final disposal of PCBs, in this process the PCB molecules decompose at high temperatures resulting in CO<sub>2</sub> and water.
- Plasmatic Arc, this technology generates a plasmatic arc between two electrodes in a gaseous medium such as argon at low pressure, generating carbon dioxide, water and an aqueous solution of sodium salts.

As a result of this bibliographic review and experiences in other countries of South America, the most used technologies for the elimination and treatment of dielectric oils with PCBs due to their technical characteristics and costs, are Dechlorination and Incineration. The countries implementing the chemical dechlorination method are Argentina, Peru and Chile, reaching an efficiency of 99.9999% for the treatment of dielectric oil and transformers that contain it. This process is carried out at low temperatures or room temperature. Some countries that carry out the PCB incineration method at temperatures higher than 1400 °C, are: Holland, France, Spain, with an efficiency of 99.9999% for the treatment of dielectric oils containing PCB. Among technologies, such as autoclaving, dechlorination, basic catalytic decomposition, supercritical water oxidation, hazardous waste incineration, and plasma arc, two widely applied methods were discussed and are described in more detail below:

### 2.3. Dechlorination

Dechlorination is one of the non-destructive decontamination processes in which the oil is free of chlorine, allowing it to be reused or recycled. This technology is based on the effect produced by the Declor K reagent, developed by an Argentine company (KIOSHI, 2002) which began its activities in 2002, in Argentina, Peru, Paraguay and Uruguay, where Decontamination has been carried out more than 20,000 tons of PCB. This technology is installed within the country that requires the service, avoiding the costs of cross-border transportation of the waste to be treated.

It uses alkali metals, on chlorinated organic compounds, which, through the Wurtz reaction, which replace the chlorine atoms present in the molecule with aliphatic structures, "dechlorinated" (KIOSHI, 2009). In this way, the dangerous characteristics corresponding to the PCB content are eliminated, also achieving the reuse of the base oil, since once treated it recovers the characteristics for its reuse as insulating oil. The

objective of this treatment is to dechlorinate the dielectric oil to concentrations below 2 ppm (parts per million) at the outlet of the system, from input concentrations up to 5,000 ppm of PCBs (0.5% w/w) with special considerations (KIOSHI, 2002). The electrical equipment to be treated is subjected to online recirculation in one or more stages until the required concentration is obtained that allow its reclassification. Once the reaction is finished and the oil is discharged, a sample will be taken to perform a PCB content analysis in an accredited laboratory.

### Residue Generation

The decontamination process itself, as it has been presented, does not generate any type of waste that contains PCBs, in proportions greater than those accepted by the regulations that govern the matter. This is due to the design characteristics of the dechlorination equipment where the reactor is the only module that is in contact with the PCB, consisting of a sealed system that maintains the reaction until the complete dechlorination of the oil (not detected, less than 2 ppm) (KIOSHI, 2002).

### Costs involved in the Dechlorination process

The metric ton of dielectric oil with PCB has a cost of 1,000 dollars and the cost of treating transformers per ton is 1,800 dollars (Kioshi, 2017).

#### 2.3.1. Incineration of hazardous waste

Currently, PCB wastes are mostly destroyed by incineration, this is because high-temperature incineration is a well-established and readily available technology in many industrialized countries (PNUMA, 2004). The most common combustion technology in hazardous waste incineration is the rotary kiln, plants in the commercial sector can process 82–270 tons of waste per day, incineration plants carry out processes of waste reception, storage, pretreatment, incineration/energy recovery, combustion gas purification, solid waste management and wastewater treatment, incinerators reach temperatures of 1400 °C. At this temperature calcination and smelting occurs (Secretariat of Stockholm Convention on persistent organic pollutants, 2008).

The oil from the transformers is separated from the country of origin, under a strict safety protocol and under all environmental guidelines, they are packaged and sealed in respectively labeled drums and in the same way the transformers are stored, in a container that will be transported by sea to the managing country. Once the PCB materials have been received in the incineration plant, the dielectric oil enters the rotary kiln for final disposal and the transformers go through a washing with a chemical solvent that removes the remains of PCB. After this process, the valuable metal parts are removed, and the casing is sold for scrap.

### Residue generation

In the incineration, carbon dioxide, water and inorganic ash are produced. Chloride present is removed as hydrochloric acid gas. If the minimum parameters of temperature, residence time and oxygen dosage are not met, other toxic substances can be generated, such as dioxins and furans, which are more dangerous persistent organic compounds than PCBs (PNUMA, 2004).

### Estimation of CO<sub>2</sub> emissions

Since Carbon Dioxide (CO<sub>2</sub>) is a greenhouse gas and aware of the environmental responsibility that the final disposal of PCBs entails, the amount of CO<sub>2</sub> that would be emitted into the environment by the incineration of 436.4 tons of PCB will be estimated, according to the type of methodology established in the 2006 IPCC (Intergovernmental Group of Experts on Climate Change) Guidelines for national greenhouse gas inventories, the equation that allows us to estimate the amount of CO<sub>2</sub> is detailed below:

In our research, we are going to use the level 3 calculation that uses plant-specific data to estimate CO<sub>2</sub> emissions from the incineration of liquid waste, using the following Equation:

Eq. (1) CO<sub>2</sub> Emissions from the incineration of liquid fossil wastes

$$\text{CO}_2 \text{ Emissions} = \sum (\text{AL}_i * \text{CL}_i * \text{OF}_i) * 44 / 12 \quad (1)$$

Source: (Intergovernmental Group of Experts on Climate Change, 2019) where:

CO<sub>2</sub> Emissions = CO<sub>2</sub> emissions from the incineration of liquid fossil wastes, Gg.

AL<sub>i</sub> = amount of type i liquid fossil waste incinerated, Gg.

CL<sub>i</sub> = carbon content of type i liquid fossil waste incinerated, (fraction).

OF<sub>i</sub> = oxidation factor for type i liquid fossil wastes, (fraction).

44/12 = conversion factor of C into CO<sub>2</sub>.

To determine the factors, we resort to the information in the following table (see Table 1).

Source: (Intergovernmental Group of Experts on Climate Change, 2019).

Whit these data we proceed to perform the calculation.

Eq. (2) Calculation of CO<sub>2</sub> Emissions

$$\begin{aligned} \text{CO}_2 \text{ Emissions} &= \sum (\text{AL}_i * \text{CL}_i * \text{OF}_i) * 44 / 12 \\ \text{CO}_2 \text{ Emissions} &= \sum (0.26554 * 1 * 1) * 44 / 12 \\ \text{CO}_2 \text{ Emissions} &= 0,9719 \text{ GG} \end{aligned} \quad (2)$$

The amount of CO<sub>2</sub> emitted into the environment by incineration of 265.54 tons corresponding to the weight of the dielectric oil, would emit 0.9719 Gg (gigagrams) to the environment, measured used for CO<sub>2</sub> emissions, this means that for each ton of PCB, 0.004 Gg of CO<sub>2</sub> are sent to the environment.

### Reference costs for the incineration process

The costs of companies that participated in the “Project to eliminate 137 tons of PCB in Ecuador” are taken as a reference, the final management cost with this technology is USD 3,800.15 per ton of PCB, and this cost includes logistics processes, legal procedures, transport and final disposal. Additionally, the environmental cost of the generation of CO<sub>2</sub> has been estimated by the incineration of 265.54 tons of dielectric oil polluting with PCB, considering that these emissions are a direct product of the final disposal process of these hazardous wastes, as a reference the costs per emission were used. tons of CO<sub>2</sub> used in the Netherlands, which is 30 euros/t of CO<sub>2</sub> emitted into the atmosphere from 2021 (Magnus commodities, 2020), these values have been taken as a reference, since Ecuador carried out a pilot shipment in the year 2017 to industries in this country.

Other economic items involved in PCB management are:

#### 2.3.2. PCB storage

The cost of storing hazardous waste was analyzed, considering the deadline until December 2020 to complete the inventory established in AM 146. Therefore, the storage costs from 2020 to 2025 were taken as the limit for final management of PCBs in Ecuador, for the storage of 55 gallons equipment or barrel the monthly cost is 61.6 dollars for private companies. Companies in the electricity sector and individuals must have the corresponding environmental permit for the storage of PCBs, if not, PCB stocks must be managed by a manager authorized by the environmental authority.

#### 2.3.3. Hazardous waste transportation

Legislation in its Art. 174 of Ministerial Agreement 061, establishes that: *Those who carry out the activity of transporting dangerous chemical substances and/or hazardous waste at the national level must obtain the environmental permit according to the Unique Environmental Management System, for the aforementioned Only managers authorized by the Competent National Authority may provide the service for the management of these hazardous wastes, the costs vary according to the distance traveled and prices can be quoted between 0.04 and 0.15 (USD/KG).*

Once the amount of transformers contaminated with PCBs and their weight in tons and the cost of treatment, transportation costs and storage

**Table 1.** CO<sub>2</sub> Emission factors for incineration and open incineration of waste.DEFAULT DATA FOR CO<sub>2</sub> EMISSION FACTORS FOR INCINERATION AND OPEN WASTE INCINERATION.

Parameters	Management practice	DMS	Industrial waste (%)	Hospital waste (%)	Sewage sludge (%) note 4	Liquid fossil wastes (%) note 5
Dry matter content in % of wet weight		See note 1	NA	NA	NA	NA
Total carbon content in % of dry weight		See note 1	50	60	40–50	80
Fossil carbon fraction in% of total carbon content		See note 2	90	40	0	100
Oxidation factor in% of carbon input.	Incineration	100	100	100	100	100
	Open incineration note 3	58	NO	NO	NO	NO

NA: Not available.

NO: Does not happen.

Note 1: Use default data from Table 2.4 of Section 2.3, Composition of waste, and Equation 5.8 (for dry matter), Equation 5.9 (For carbon content) and Equation 5.10 (for fossil carbon fraction).

Note 2: The default data by type of industry is provided in Table 2.5 of Section 2.3, Waste Composition. To estimate emissions, use the equations mentioned in Note 1.

Note 3: When the waste is subjected to open incineration, the weight of the waste is reduced by approximately 49–67 percent. A default value of 58 percent is suggested.

Note 4: See Section 2.3.2 Sewage Sludge, Chapter 2.

Note 5: The total carbon content of liquid fossil waste is given in percent of wet weight and not in percent of dry weight.

costs has been determined, we proceed to calculate the costs involved in the management of these polluting wastes.

### 3. Results and discussion

#### 3.1. PCB inventory

This process has meant greater economic and technical efforts for electric companies nationwide; AM 146 establishes a time limit to comply with the total characterization of PCBs in the country, thus establishing compliance goals.

The total number of transformers in the inventory is 216,632, the national legislation established 3 different deadlines to gradually comply with the characterization of the transformers and the reporting of their results on the SNIS-PCB platform. By 2016, the number of transformers that had to be analyzed was 40%, in 2018 it was 70% and finally by 2020 the analysis of 100% of the inventory must be met. However, the characterization process is not complete, which represents a limitation for the research, up to the date of the research in 2018, in the SNIS-PCB system 90,348 transformers are analyzed, equivalent to 41% of the inventory, there are 3,494 transformers with positive result for PCB equivalent to 436.4 tons of PCB.

#### 3.2. Technical feasibility of technologies for the treatment and final disposal of dielectric oils with PCB

##### 3.2.1. Dechlorination

This treatment technology for dielectric oils contaminated with PCBs (concentrations greater than 50 ppm) requires technical conditions that allow the decontamination of the dielectric and transformer oil, such as:

- The concentration of the dielectric oil must be up to 200 ppm, before being exposed to the treatment, in the inventory review we have contaminated transformers that meet this requirement.
- The quantity of dielectric oil must exceed 400,000 L or 110,000 gallons.
- Final PCB concentrations after the treatment has been carried out will be less than 40 ppm in dielectric oils for co-processing and transformers and less than 2 ppm for dielectric oils that are destined for reuse in transformers.
- The dechlorination process will be carried out in one geographic location, that is, according to the conditions of the electricity companies, one will be chosen, which has the space and technical specifications to establish the technology. In this place it will be carried out the collection and treatment of transformers and tanks with polluted dielectric oil.

#### Advantages of this process

- Does not emit harmful gases into the atmosphere.
- Reduces the generation and final disposal of hazardous waste.
- Improves the economic and financial equation of the company against the export of transformers and/or contaminated dielectric oil.
- Allows the regeneration of mineral oil, recovering a non-renewable resource.
- Recovery of the transformer, since, in a later stage, as the oil is regenerated, the transformer can be reclassified according to the international standards with extensive antecedents in the matter, citing as an example the regulations of the States USAPA 40761 CFR, where transformers are reclassified after 90 days of decontamination treatment.
- The concentration is reduced up to 2 ppm in transformers, as their particular characteristics allow it. Finally, this waste minimization criterion must be understood as an important success since non-renewable resources are scarce goods whose recovery and reused generates long-term sustainability.

These criteria are contemplated not only by legal regulations, but are the pillars of voluntary regulations on environmental management (Kioshi, 2017).

##### 3.2.2. Incineration of hazardous waste

This destruction technology allows the irreversible transformation of a wide range of waste, depending on its calorific value. However, such destruction does not lead to the total absence of waste, but this is a general characteristic of any treatment system.

#### Advantages of the process

- With incineration, a significant decrease in the final volume of waste is achieved with respect to the processed quantities (of the order of 90% volume and 70% weight) and the elimination or substantial reduction of the danger of these.
- Allows efficient control of the emissions of gaseous products into the atmosphere, minimizing environmental impact.
- It allows an immediate reduction of hazardous waste, which does not require long periods of residence time (Secretariat of Stockholm Convention on persistent organic pollutants, 2008).

#### Process disadvantage

- It can be difficult to distinguish between the biogenic and fossil components of waste destined for incineration; the data necessary to determine these fractions can be obtained from the analysis of waste available in many countries. However, actual data on the origin of the waste is often lacking, or existing data is out of date (Bigg &

**Table 2.** Technical comparison of Dechlorination and Incineration technologies.

Technical comparison of treatment/disposal technologies		
Parameters	Dechlorination	Incineration
Technology efficiency	99.99%	99.99%
Waste Generation	Does not generate waste	Generates waste
Generation of gases to the environment	no	yes
Reuse of oil	yes	no
Reuse of housing	yes	no
On- site operation	yes	No (export must be performed)
Emission of gases into the atmosphere	no	yes
Performance in an 8- hour work day	343 gal or 1.23 tons	176 tons

Paciornik, IPCC Guidance on Good Practices and Managing Uncertainty in National Greenhouse Gas Inventories., 2005).

- If the final disposal of PCBs is incineration, export guidelines should be taken into account, since the technology is found in developed countries.
- The waste generator (company or natural person who owns PCB waste) must contract and authorize one or more management and authorized companies to carry out all the preparation work (including the processing of cross-border transport permits), handling, transportation (land and sea) and final disposal of waste.
- It is considered as a disadvantage, that one of the products of incineration is carbon dioxide (CO<sub>2</sub>), since these emissions are not monitored directly, and to know the impact it causes on the environment it is calculated from the total carbon content of waste (Bigg & Paciornik, IPCC Guidance on Good Practices and Managing Uncertainty in National Greenhouse Gas Inventories., 2005).
- The incineration of 265.54 tons of dielectric oil with PCBs determined in this study would emit 0.9719 Gg into the environment, this means that 0.004 Gg of CO<sub>2</sub> is emitted into the environment for each ton of PCB.

The technologies are compared in terms of efficiency in Table 2, we find the most relevant characteristics that allow determining the technology for the treatment or elimination of PCBs.

As detailed in Table 2, the technology that allows the recovery of resources is dechlorination, which can lead into economic savings for companies in the replacement of transformers and dielectric oil, it is a technology that reaches 99.99% efficiency and It is friendly to the environment by not generating waste and CO<sub>2</sub> emissions.

### 3.3. Economic feasibility of the chosen technologies

The cost information has been provided by the companies that carry out the dechlorination and incineration technologies. In Table 3, costs for treatment, transport and storage are presented, with this information an economic analysis can be obtained and determine, in terms of efficiency, the technology that can be applied in the country.

It should be mentioned that the cost of the incineration technology includes the costs of transporting the waste, which is why they are not detailed in the table.

#### 3.3.1. Comparison of costs by technology for the final disposal of PCB

##### Dechlorination costs for PCB

In accordance with the guidelines of the company that carries out this process, the dielectric oil and transformers are managed separately; therefore, their cost is different. Table 4 details the costs of treating dechlorination for oils and transformers.

The cost of the treatment by dechlorination for 436.4 tons of PCB is 638,489.50 dollars, the dechlorination of one (1) ton of PCB has a cost of 1,463.10 dollars.

#### 3.4. Incineration costs for PCBs

The incineration of 436.4 tons of PCB would be of 1,658,271.50 dollars, meaning that the incineration of 1 ton of PCB has a cost of 38,000 dollars. To this item, for PCB removal must be added the environmental cost for CO<sub>2</sub> emissions caused by the incineration of 265.54 tons of dielectric oil with PCBs and the environmental cost of the emissions of 971.9 tons of CO<sub>2</sub> from the incineration of 265.54 tons of PCBs would be \$ 34,628,797.

**Table 3.** PCB Treatment and/or disposal costs.

Treatment and/or disposal conditions		
Technology	Treatment costs	Transportation
	Costs/ton USD	Costs/ton USD
Oil dechlorination	1,000	150
Dechlorination of Transformers	1,800	150
Incineration	3,800.15	0

Presentation of costs for PCB final disposal.

**Table 4.** Dechlorination treatment costs for PCBs.

	Unit (Ton)	Dechlorination costs USD	Transportation USD	Total, costs USD
Dielectric oil with PCB	265.54	265,540	39,831	305,371
Transformers with PCB	170.83	307,494	25,624.5	333,118.5
Total				638,489.5

### 3.5. Private PCB storage cost

According to the study, electricity companies and individuals must manage their PCB stocks until 2020, for the inventory of private companies the information provided by the PCB Project was used, which included 1,063 transformers weighing 276.80 Tons. for the cost of the storage of private transformers, taking into account that in 2020 the inventory must conclude at national level, it was considered 5 years of maximum storage established in AM 146, once this time has expired, the control bodies must carry out the management for the final disposal of all PCB stocks in Ecuador.

The cost of PCB storage for private holders would be 3,928,848 dollars for 5 years of storage until its final disposal, this means that 1 ton of PCB has an annual storage cost of 2,838.8 dollars. These results allow us to conclude that a timely characterization of transformers makes it possible to determine an appropriate technological option for PCBs and avoid unnecessary and excessive spending on PCB storage during the term established in AM 146.

## 4. Conclusions

- The national inventory of PCB includes a total number of 216,632 transformers belonging to the electrical companies registered in the SNIS-PCB system, 90,346 transformers are characterized per year of the study, which is 2018, equivalent to 41% of the total inventory and of the same 3,494 transformers have concentrations greater than 50 ppm of PCB equivalent to 436.4 tons of PCB.
- The minimum technical specifications required for the quantity and weight of PCB, maximum concentration, physical conditions of the place to carry out the treatment, as well as the technical specifications of the process, determine that the Dechlorination technology can be implemented in Ecuador.
- The Dechlorination technology presents the best economic offer for the final disposal of the 436.4 tons of PCB at a cost of 638,489.50 dollars compared to the incineration technology, which yields an amount of 1,658,271,456 dollars.
- In the present investigation, the PCB storage costs were analyzed, for private owners, this must be carried out with a qualified environmental manager, the timely characterization of the transformers until 2020, allows the saving of 2,838.80 dollars for the annual storage for every ton of PCBs.

## Declarations

### Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

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### Data availability statement

Data included in article/supplementary material/referenced in article.

### Declaration of interests statement

The authors declare no conflict of interest.

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