STUDY ON THE MANAGEMENT OF ELECTRICAL EQUIPMENT AND WASTE ELECTRICAL EQUIPMENT WITH PCB CONTENT IN MARAMUREȘ COUNTY, ROMANIA

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Abstract*: This study highlights the management of electrical equipment and waste electrical equipment with PCB content inventoried in Romania. Because it is mandatory to phase out such equipment with concentrations of at least 50 ppm at a volume of more than 5 dm^3 an assessment of the compliance with the requirements imposed by the specific legislation has been made. The results obtained from the statistical processing and interpretation of the data from the national inventory reveal that in Romania, the elimination process is slow and that are still important stocks of equipment with PCB content that must be eliminated. By the end of 2018, the rate of decontamination and disposal of this equipment and the quantities of oils with PCB content was below 25%. Currently, there is no national or county inventory of fluid-containing equipment with 0.005% to 0.05% PCB relative to fluid weight. In Maramureș County, there is no waste electrical equipment in the inventory with PCB content, but only capacitors in use. By the end of 2019, the rate of decontamination and disposal of these equipments at county level was below 15%.*

1. INTRODUCTION

PCBs belong to a wide family of man-made organic chemicals, known as chlorinated hydrocarbons. They belong to the category of persistent organic compounds and consist of

carbon, hydrogen and chlorine atoms. The number of chlorine atoms and their location in a PCB molecule determine many of its physical and chemical properties [1-2].

The chemical formula of PCBs is $C1_2H_{10-n}Cl_n$, where *n* ranges from 1 to 10. From 209 possible congeners only 130 have been identified in commercial products [3].

PCBs are notable for being extremely persistent, bioaccumulating and transferring to the food chain, easily transported over long distances in the environment, seriously affecting environmental factors and human health. [4-5].

No natural sources of PCBs are known, they are synthetic products. In appearance and condition, PCBs are either in the form of an oily liquid or in solid form or even in volatile form, being present in the air as vapors. The color varies from colorless to light yellow. They have no taste or smell [5].

Due to their high flash points (170–380 °C) PCBs are fire resistant. They are characterized by low electrical conductivity, high thermal conductivity and high resistance to thermal degradation. Thus, they have been used as dielectic isolators in electrical devices [3].

Being used commercially since 1929, after the finding and demonstration of the spread of PCBs in the environment and in living beings in 1966, the production of equipment containing PCBs was banned in 1979 [3], [2]. Thus, many countries have stopped the production, marketing and use of these compounds [3].

In Europe, the production and marketing of PCBs have been severely restricted since 1985 [6]. However, PCB contents continue to exist in old equipment or equipment waste, especially in electrical equipment such as: transformers, capacitors, voltage regulators, circuit breakers, reclosers, insulators; old electrical devices or apparatus containing PCB capacitors [2].

European environmental policy aims at the controlled disposal of PCBs, ie the decontamination or disposal of equipment containing PCBs [7], [1], [8].

Thus, Directive 96/59 / EC requires Member States to draw up registers for equipment containing more than 5 dm^3 of PCBs and to ensure that such equipment has been decontaminated or disposed of by 31.12.2010 at the latest [1].

By the Stockholm Convention (2001), and subsequently under Regulation no. 1021/2019 was established by the end of 2025 at the latest the gradual elimination of the use of polychlorinated biphenyls (PCBs) in equipment (e.g. transformers, capacitors etc). More precisely it is the equipment that contains residual PCB stocks of over 0.005% and in of more than 0.05 dm^3 [6], [8].

In support of the inventory of PCB oils contained in electrical equipment, the Global Environment Facility (GEF) has implemented the project “PCB Elimination in Romania) [9]. Also, by Order no. 1179/2010 was approved the Guide on the Rational Ecological Management of Polychlorinated Biphenyls (PCBs) which has the role of supporting the introduction of a management system for the evidence, monitoring and rational ecological elimination of electrical equipment contaminated with PCBs in Romania [9].

In accordance with the European List of Wastes provided for in Decision 2000/532 / EC and GD no. 856/2002 wastes of electrical equipment containing PCBs are classified as follows [10-11]:

16 02 09* transformers and capacitors containing PCBs

16 02 10* scrapped equipment containing PCBs or contaminated with PCBs, other than those specified in 16 02 09

In Romania, all equipment and waste containing PCBs in concentrations of at least 50 ppm at a volume of more than 5 dm^3 or those containing fluids with 0.005% to 0.05% PCB relative to the weight of the fluid must be inventoried for monitoring, decontamination or disposal [12].

In order to ensure the elaboration, updating and publication of the National Inventory of equipment and materials containing designated compounds, the Secretariat for designated compounds has been established at national level [12-13].

According to the National Plan for the implementation of the provisions of the Convention on Persistent Organic Pollutants, adopted in Stockholm on May 22, 2001, Romania has set as its major objective the elimination of equipment containing PCBs. Correlated with the field of energy distribution, this elimination cannot be done suddenly, but required a staging of the actions, as follows [14]:

1. By 2025, phasing out PCB-containing equipment in operation by replacing it with PCB-free equipment.
2. By 2029, updating inventories of equipment holding PCBs (functional or obsolete).

To fulfill these obligations, both the public environmental protection authorities (central, national, and territorial) and the inspection and control, respectively the economic operators have attributions [14]. For instance, the Electrica Corporation aims as a major objective regarding the protection of the environment the gradual withdrawal from operation, until 2028, of the equipments containing PCB, according to the legal provisions and the national elimination program [15].

Also, the economic operators have the obligation to label equipment in operation or in conservation that contains designated compounds in quantities greater than the minimum quantities [12].

Given the effects and restrictions on the use of PCB oils, solutions are increasingly being sought to replace them with environmentally friendly and safe products for human health. In this regard, Brazilian researchers Da Silva and Sá, (2020) conducted an experiment using natural esters instead of PCB-containing oils. Replacement of PCB oils in transformers with natural or synthetic esters also supported by other experts and researchers [16-21].

The objective of the present study is to identify the current state of waste electrical equipment management in Maramureș County and Romania and the degree of its compliance with the legislative provisions in force.

2. MATERIALS AND METHOD

The conduct of this study is based on information from the specialized scientific literature and on raw inventory data of electrical equipment with PCB content at national and county level. The main source for statistic data is the national inventory of PCB provided by National Environmental Protection Agency.

The method used is that of documentation, data collection, statistical processing and interpretation.

3. RESULTS AND DISCUSSION

3.1 Technical properties of PCBs in electrical equipments

Power transformers are the most important equipment in the electricity transmission chain from producer to consumer. Their role is to change the voltage level so transportation and distribution of the energy be with maximum efficiency. They are made of two main types of active materials: the conductors (Cu or AL) needed for the electrical circuits and the ferromagnetic core, necessary for closing the magnetic flux. In addition to these main materials, insulating materials have a particularly important role. They ensure the insulation between the coil turns but also between the different electrical circuits or between them and the ground.

On the other hand, medium voltage capacitors are used in electrical installations for compensating the power factor. Because the capacitance value is directly proportional with the electric permittivity and the plates surface and inverse proportionally with the distance between plates, it is obviously that dielectric material highly influence the volume of capacitors for an imposed voltage and capacitance.

In the operation of medium and high voltage power transformers, due to the large potential differences between the different active parts as well as between the active parts and the ground, intense electric fields appear that require materials with good insulating properties. Also, during operation, the current in the windings, as well as the variable magnetic flux in the magnetic core, produce electrical losses (proportional to the square of the current and of the voltage respectively) which in time lead to an increase in their temperature. Maintaining a temperature below the limit one, decided by the insulation class, impose the transfer of the heat to the outer surface of the tank and then to the environment. These phenomena (all or some of them) are also valid in the case of other medium or high voltage electrical equipment such as capacitors, switches etc.

PCBs were widely used by manufacturers as dielectric material in power transformers, capacitors, and other electrical apparatus (predominantly in enclosed systems). There are some

main characteristics that recommend the use of PCBs: very good electrical insulating properties, good heat transfer, nonflammability, high boiling point, and chemical stability[22]. Possessing the properties above mentioned, these liquids provide three main functions in electrical devices: offers insulation between active parts at different potentials and also protecting from corrosion of metallic areas; transfers the heat from core and conductors to enclosing container exterior surface; behaves as a healthiness index for equipment. By monitoring the analysis of liquid, the state of electric equipment can be constantly monitored[22].

Of course, the PCBs weren't the first liquids used as dielectric, but they prevailed about fifty years[23] (from 1929) because of high dielectric strength and nonflammability property, from this last point of view being much better than other existing materials at that time. Being not flammable, they were used especially in devices intended to operate at sensitive places, where a fire would have become a catastrophe (hospitals and shopping malls).

The main causes of accidents involving transformers or capacitors with PCBs are arc explosions and fires. Arc explosions are caused by voltage imbalance or resonance in the high-voltage circuit due to harmonic currents [24]. Capacitor banks are normally protected by unbalance relays, but if they are not properly accorded or are defective, the explosion can occur [24]. Fires implying PCBs transformers or capacitors are most often caused by external causes (electric cables and other ignition sources).

3.2 The management of electrical equipment with PCB content at national and county level

Romania, as an EU Member State, has the obligation to follow the provisions of the Directive on the elimination of polychlorinated biphenyls and polychlorinated terphenyls (PCB / TPC) [7].

a) *b)*

Fig. 1. Transformer (a) [25]; b) [26]

Fig. 2. PCBs capacitors in Maramureș county

At national level an inventory was made of equipment and waste electrical equipment with PCB content that focused mainly on the number of capacitors, transformers, the amount of oil with PCB content held by them, the number of functional transformers and capacitors and removed used for decontamination and disposal by incineration, the amount of oil containing PCBs in the inventoried electrical equipment both functional and obsolete, respectively the amount of oil containing PCBs contained in equipment that has been decontaminated or disposed of incineration [27].

Statistical data at national and county level indicate that electrical equipment containing PCBs, both functional and obsolete, continues to be decontaminated and disposed of in order to achieve the goal of total disposal by 2025 [6], [8], [14]. Although efforts have been made in this regard, statistical data indicate a slow pace of disposal of such equipment in use or waste equipment.

From the statistical processing the interpretation of the data from the National Inventory of equipment and equipment waste with PCB content for the period 2016-2018, it results that at national level there are inventories of transformers and capacitors with PCB content both functional and obsolete and at county level Maramureș is only found in capacitors in use. All transformer and capacitor waste was collected and sent for decontamination and disposal [27].

Romania does not currently have an inventory of equipment and equipment waste containing fluids with 0.005% up to 0.05% PCB [27].

As can be seen in *Figure 3*, the number of capacitors in use with PCB content, inventoried in the period 2016-2018 in Romania, is decreasing. If in 2016 their number was about 34000 pieces, in 2018 it reached less than 32000 [27].

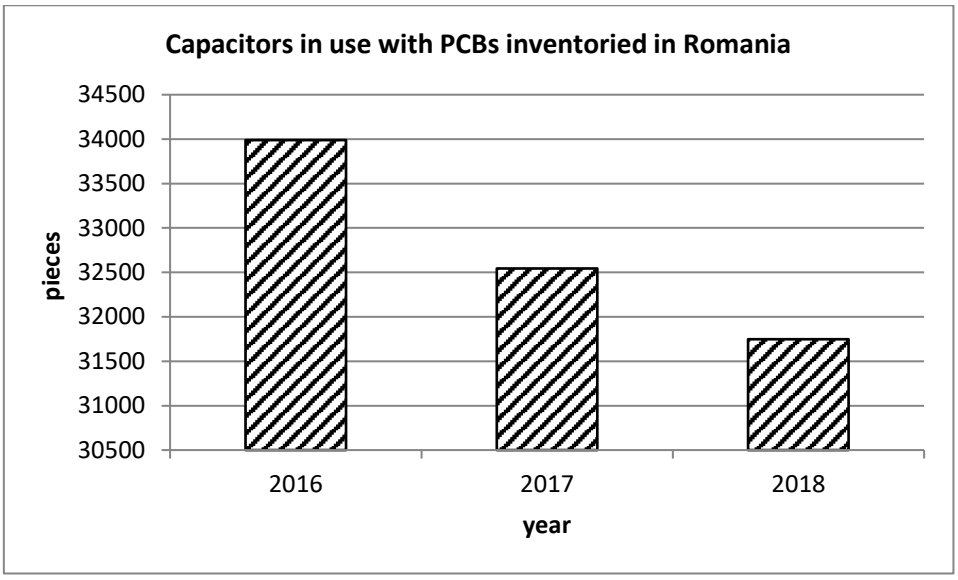

Fig. 3. Capacitors in use inventoried in Romania during 2016-2018 [27]

Regarding the degree of decontamination and incineration elimination of functional capacitors, *figure 4* shows that the highest rate of these processes was recorded for 2018 when 12.41% of the total number of capacitors were decontaminated and eliminated by incineration. The lowest rate of decontamination and elimination of functional capacitors was in 2017 with 2.47% of the total number of functional capacitors inventoried (*fig. 4*).

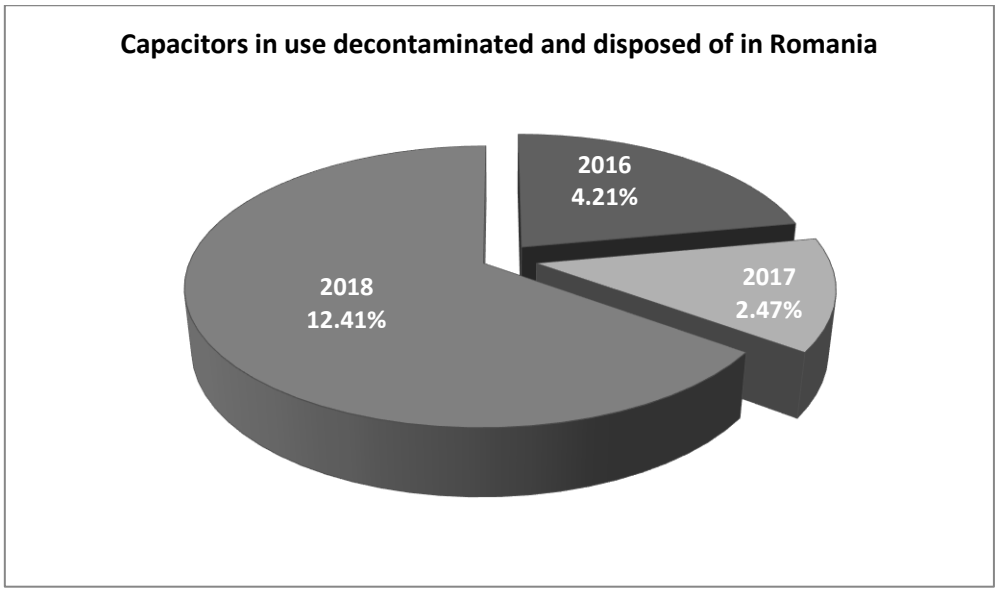

Fig. 4. Capacitors in use decontaminated and disposed of in Romania in the period 2016-2018 [27]

According to the data provided by NEPA (2021), the oil content of PCBs in the capacitors in operation inventoried in Romania in the period 2016-2018 registered a downward trend, following the decrease of the number of capacitors in use, inventoried [27]. The year 2018 recorded the lowest amount of PCB oil contained in the inventoried equipment, below 263000 liters, and the highest amount belongs to 2016 with over 300000 liters (*fig. 5*) [27].

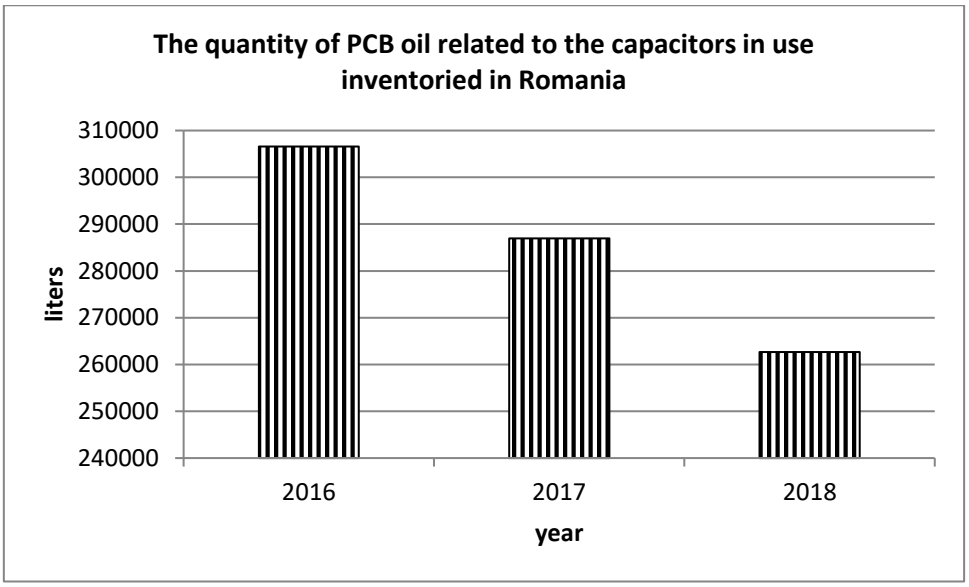

Fig. 5. The quantity of PCB oil related to the capacitors in use inventoried in Romania in the period 2016-2018 [27]

Regarding the oil content with PCBs in the capacitors in use inventoried at national level, the highest amount decontaminated and eliminated by incineration was registered for 2018 of 8.20% and the lowest, in 2017 of 2.41% (*fig. 6*) [27].

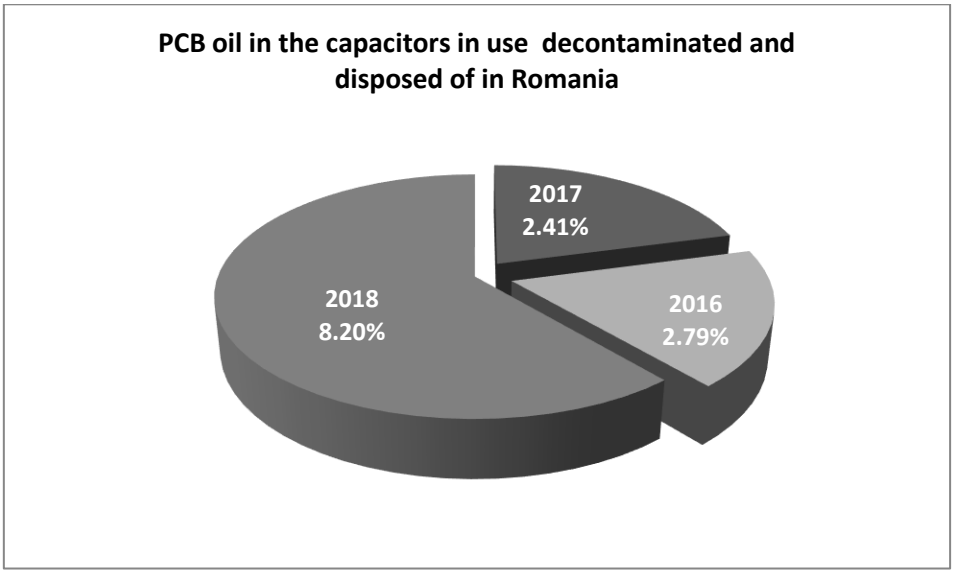

Fig. 6. PCB oil in capacitors in use, decontaminated and disposed of in Romania in the period 2016-2018 [27]

In addition to capacitors, the National Inventory also contains data of electrical transformers with PCB content. Thus, in the case of transformers in use, the statistical data for the period 2016-2018, reflect a decrease in the number of these equipments from over 540 in 2016 to 478 in 2018 (*fig. 7*) [27].

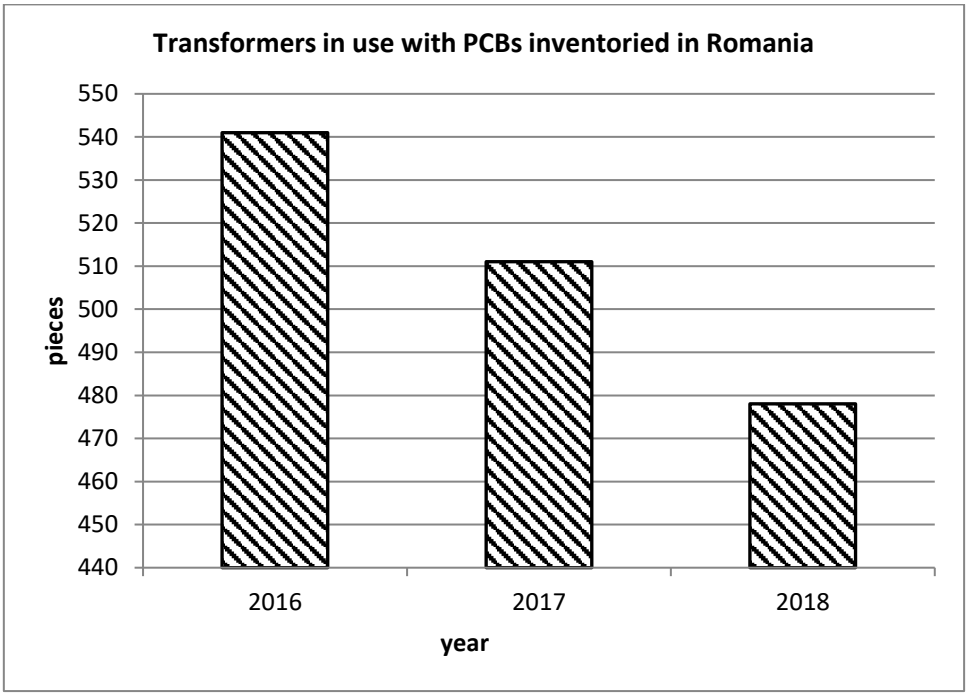

Fig. 7. Transformers in use inventoried in Romania during 2016-2018 [27]

Regarding the decontamination and disposal by incineration of transformers with PCB content in use, the highest rate was recorded in 2018 being 9.41% of the amount of inventories inventoried, respectively the lowest rate in 2017 of 2.74% (*fig. 8*) [27].

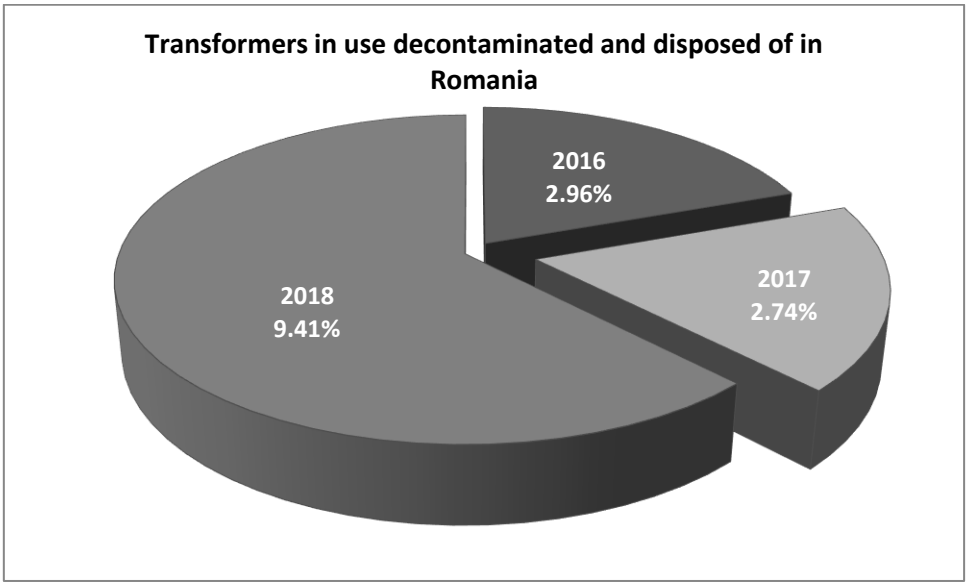

Fig. 8. Transformers in use decontaminated and disposed of in Romania in the period 2016-2018 [27]

As about the quantity of oil with PCB content in the transformers in operation in Romania, there is a decrease in the quantity in a trend very close to that of the decrease in the number of electrical equipment containing this type of oil. The lowest quantity was registered for 2018 with over 613000 liters and the highest for 2016 when 677404 liters were registered (*fig. 9*) [27].

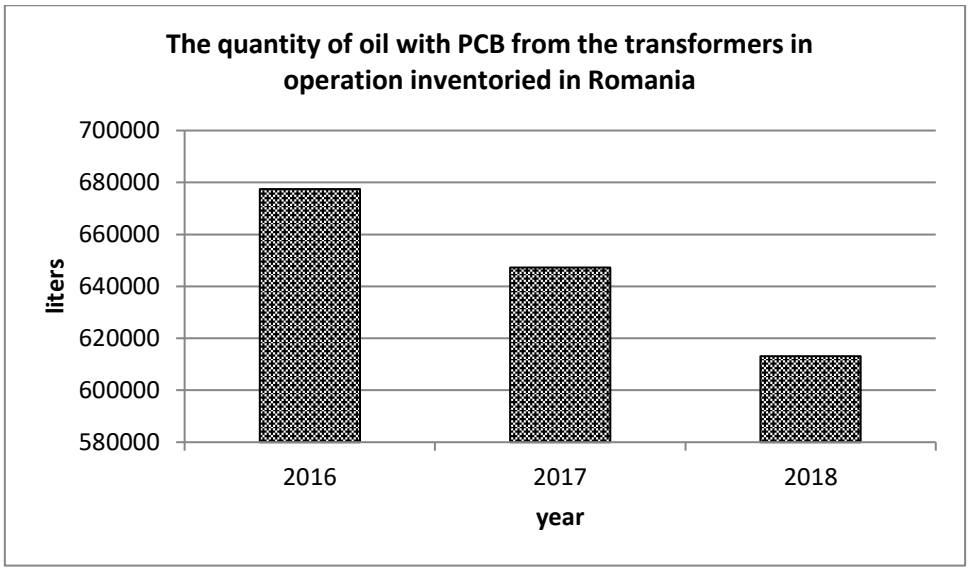

Fig. 9. The quantity of oil with PCB from the functional transformers inventoried in Romania in the period 2016-2018 [27]

Of the total amount of PCB oil inventoried for the transformers in use, the highest amount of PCB oil decontaminated and disposed of by incineration was found to be in 2018 with 11.62% and the lowest in 2017 with 2.25% of the amount of oil containing PCBs in the equipment inventoried in those years (*fig. 10*) [27].

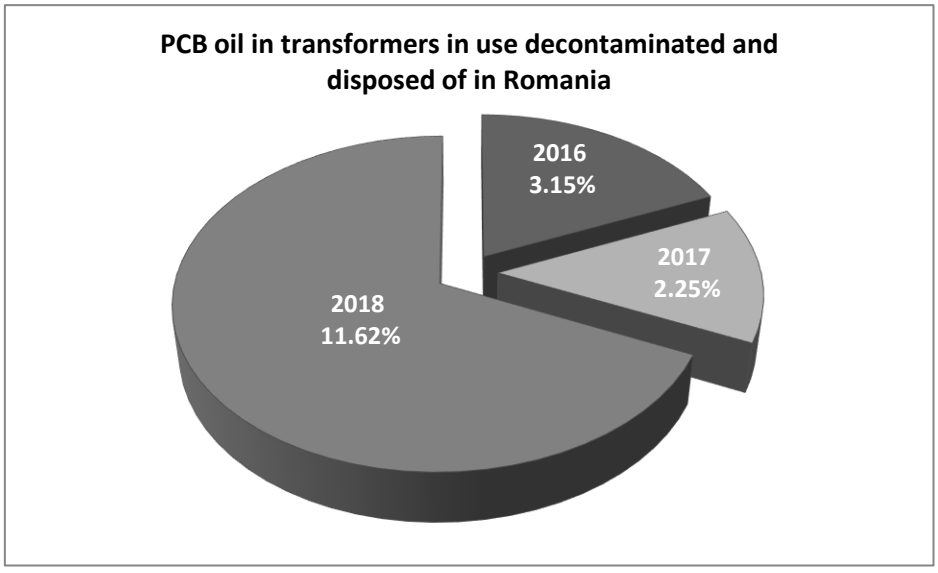

Fig. 10. PCB oil in functional transformers, decontaminated and disposed of in Romania during 2016-2018 [27]

Regarding the waste capacitors, it can be stated that their number is much lower than those in use, which is explained by the fact that the frequency of their collection was much higher. The evolution of the number of discontinued capacitors inventoried in the period 2016-2018 is a descending one, 2018 being the year in which there were the lowest number of such equipment in Romania (*fig. 11*) [27].

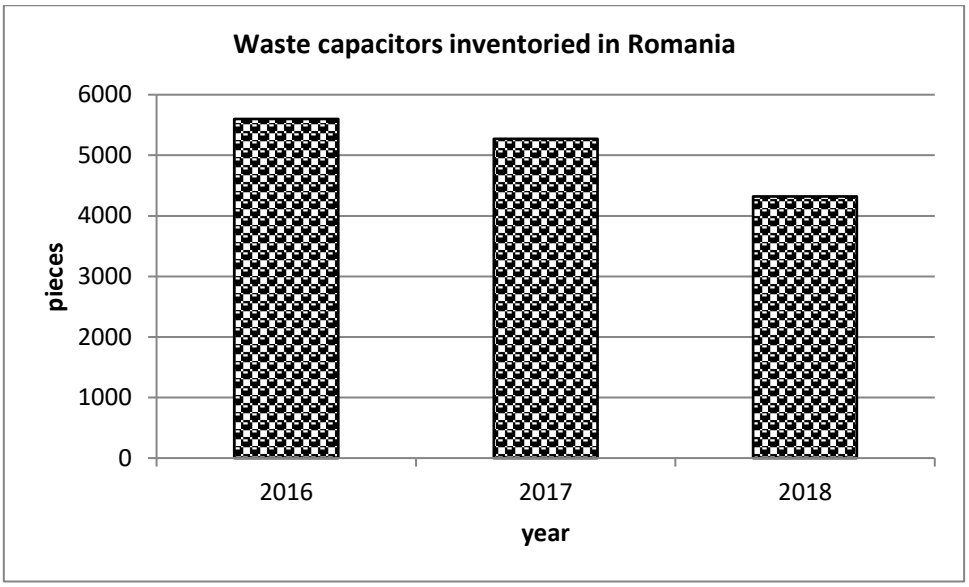

Fig. 11. Waste capacitors decontaminated and disposed of in Romania in the period 2016-2018 [27]

Compared to the number of capacitors with PCB content taken out of use in Romania, the decontaminated and eliminated ones represent a relatively small share. Thus, the highest rate of decontamination and disposal of discontinued PCB capacitors took place in 2017 of 10.28% and the lowest of 3.31% in 2018 (*fig. 12*) [27].

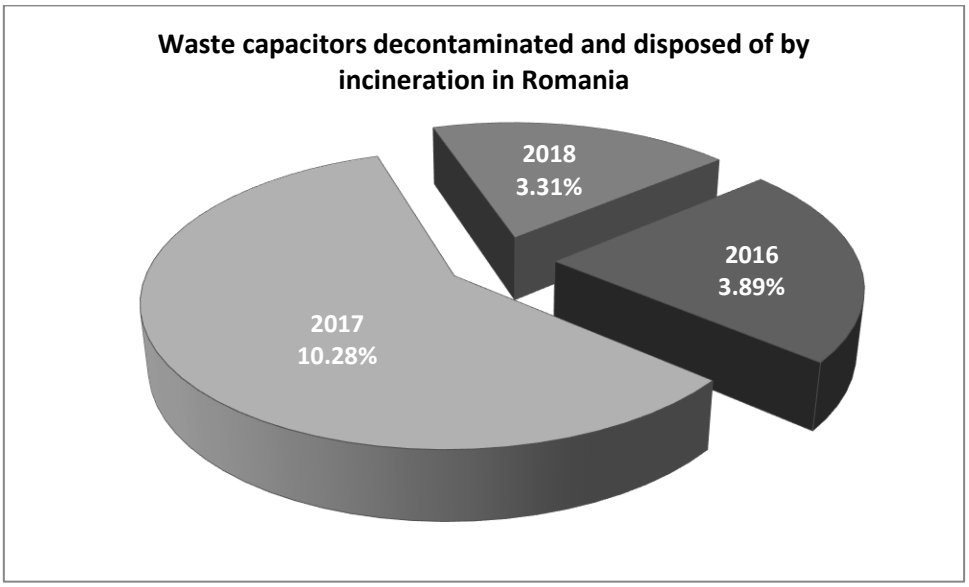

Fig. 12. Waste capacitors decontaminated and disposed of in Romania in the period 2016-2018 [27]

The quantities of PCB oil in the decommissioned capacitors have registered a decreasing trend from 2016, with over 40000 liters, until 2018 when a quantity of 32933 liters was inventoried (*fig. 13*) [27].

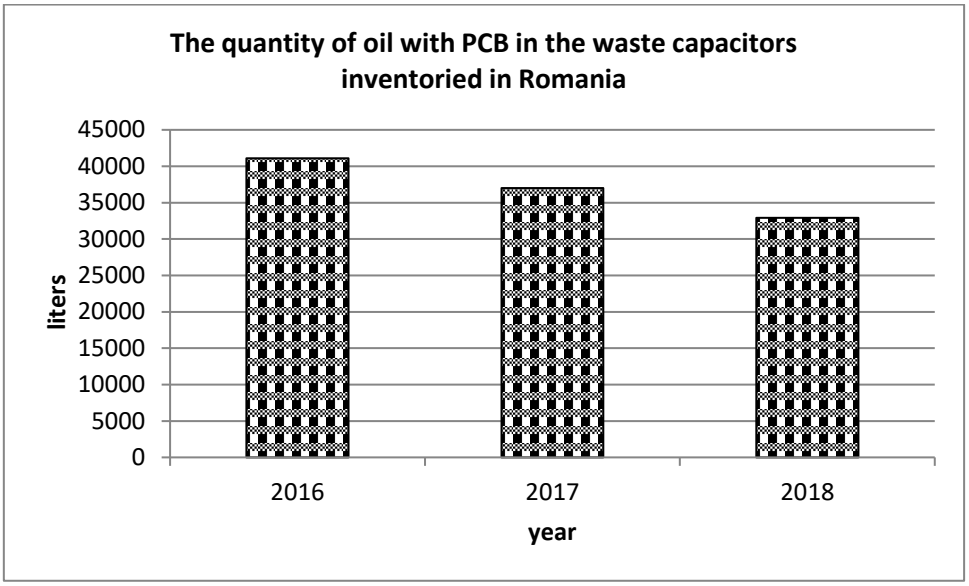

Fig. 13. The quantity of PCB oil in waste capacitors inventoried in Romania in the period 2016-2018 [27]

Some of the oil containing PCBs in the inventoried capacitors was decontaminated and disposed of by incineration in the same time with decontamining and disposing of the waste capacitors. The amount of decontaminated and incinerated oil was highest in 2017 of 8.04% of the inventoried quantity and the lowest in 2018 was 2.96% (*fig. 14*) [27].

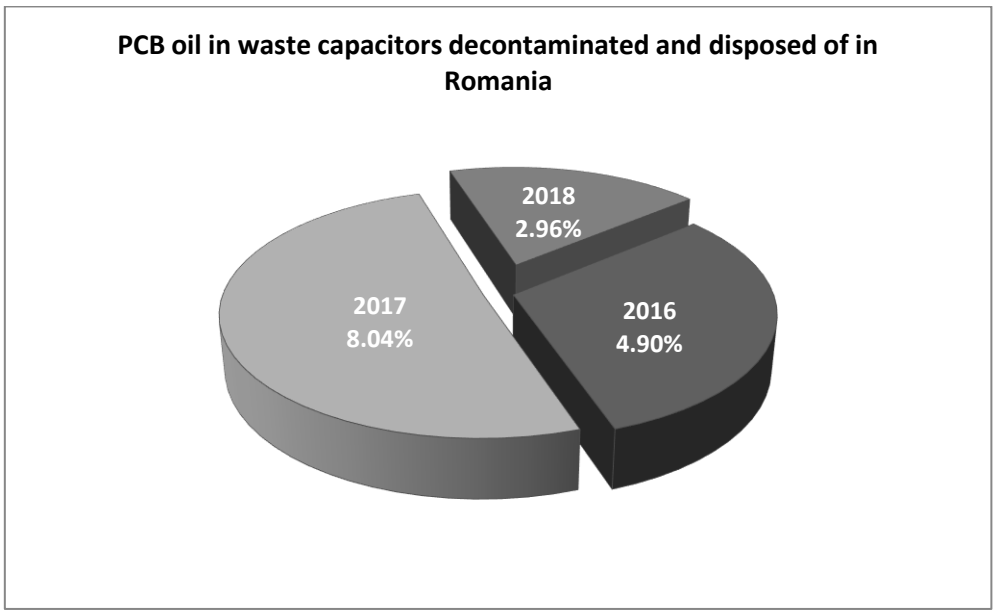

Fig. 14. PCB oil in waste capacitors decontaminated and disposed of in Romania in the period 2016-2018 [27]

In the case of waste transformers, the statistical data indicate an increase in their number in 2017 compared to 2016 and 2018. However, the largest number of transformers inventoried in the period 2016-2018 does not exceed 40 pieces / year (*fig. 15*) [27].

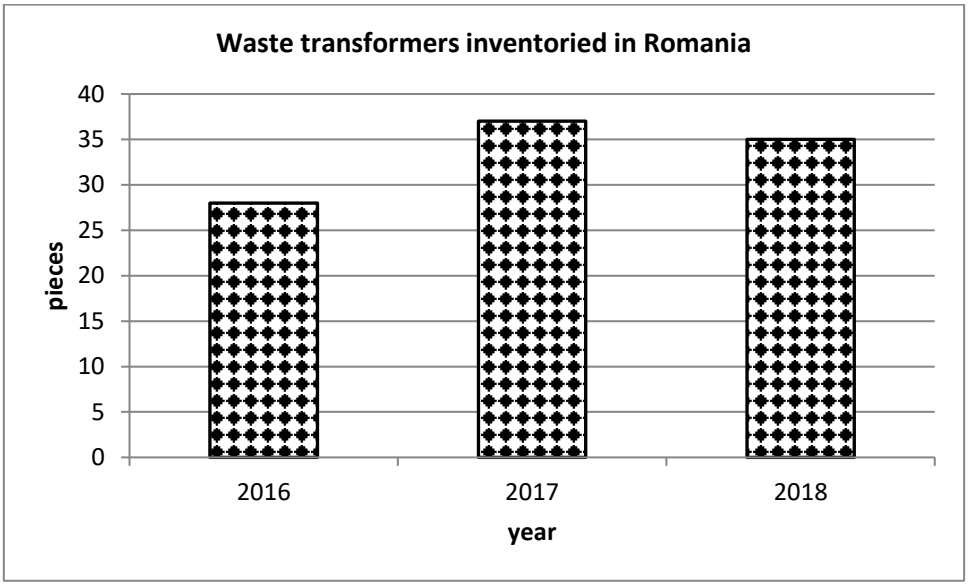

Fig. 15. Waste transformers inventoried in Romania during 2016-2018 [27]

Of the total waste transformers inventoried in Romania for the period 2016-2018, 21.43% were decontaminated and disposed of by incineration in 2016, 24.3% in 2017 and they were no longer decontaminated and disposed of in 2018 although there were 35 of such equipment in stock (*fig. 16*) [27].

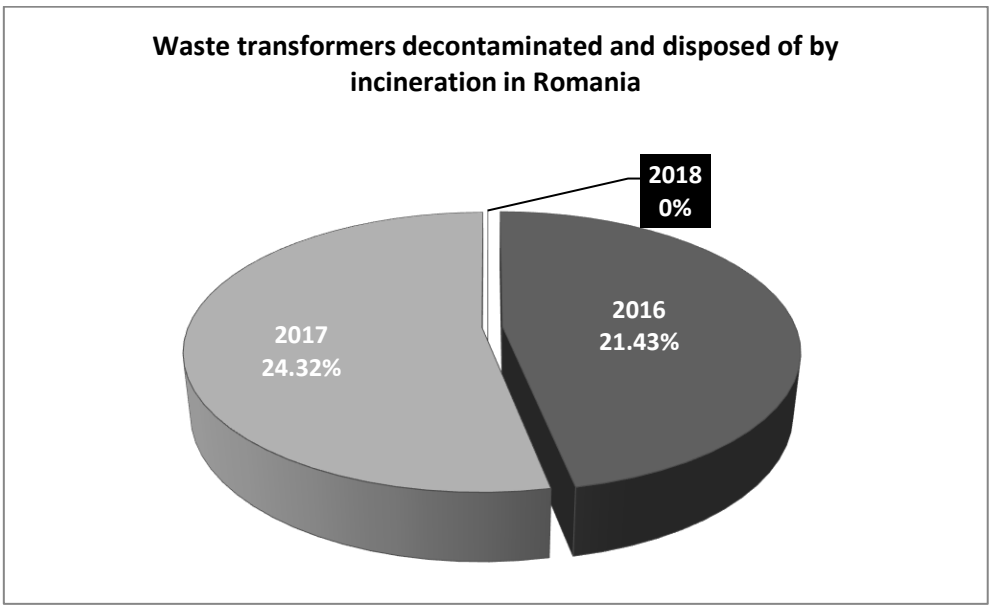

Fig. 16. Waste transformers decontaminated and disposed of in Romania in the period 2016-2018 [27]

Regarding the waste transformers inventoried in Romania in the period 2016-2018, the oil content with PCB registered an increase from over 11500 liters in 2016, to over 18800 liters in 2018 (*fig. 17*) [27].

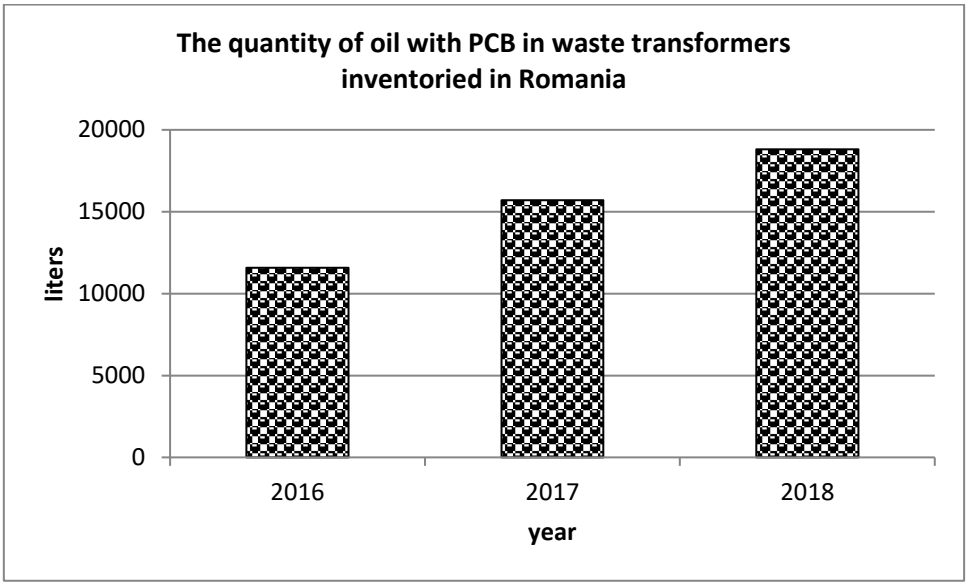

Fig. 17. The quantity of oil with PCB in waste transformers inventoried in Romania in the period 2016-2018 [27]

Of the total amount of PCB oil contained in the inventoried waste transformers, only a part of this was decontaminated and disposed of by incineration together with the decontamination and disposal of this equipment. The highest rate of decontamination and disposal was of 41.17% in 2016, of 3.21% in 2017 and it was not decontaminated and eliminated at all in 2018 (*fig. 18*) [27].

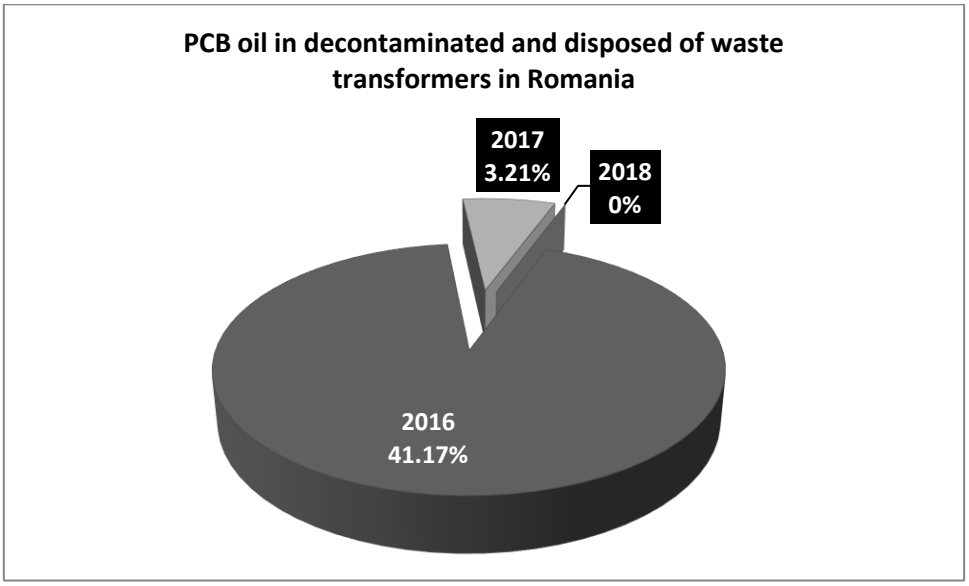

Fig. 18. PCB oil in decontaminated and disposed of waste transformers in Romania in the period 2016-2018 [27]

According to the statistical data presented above, it can be seen that the number of capacitors inventoried in Romania in the period 2016-2018 is much higher than that of transformers inventoried for the same period. This is a normal thing because of the greater number of capacitors used in medium voltage electrical installation.

According to the information provided by APM MM (2021), in Maramures county there were 6 economic operators in the period 2019-2020 that reported information regarding capacitors with PCB content [27].

In 2019, no equipment with PCB content was eliminated and in 2020, 121 capacitors were sent for decontamination, but it is possible that this number will increase because the reporting period has not been ended [27].

The inventory of electrical equipment with PCB content related to Maramureș County has no transformers with PCB content but only capacitors with PCB for the period 2016-2019 [27-28]. As shown in the graph below (*fig. 19*), there is a decreasing trend in the number of functional capacitors with PCB content. The largest number of capacitors of this type was registered with 769 pieces in 2016 getting to 637 pieces in 2019 [27-28].

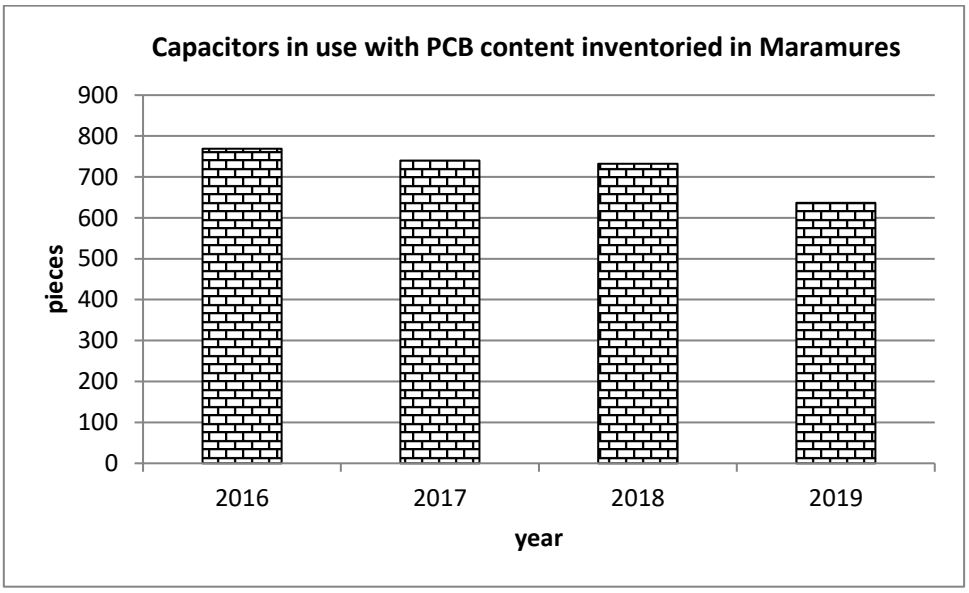

Fig. 19 Capacitors in use inventoried in Maramureș County during 2016-2018 [27-28]

Regarding the quantity of PCB oil in the waste capacitors inventoried in Maramureș County, the largest inventoried quantity was over 12747 liters in 2016 and the lowest, of 11477 liters in 2019 (*fig. 20*) [27-28].

Compared to the amount of oil contained in the capacitors in use in Maramureș County, the inventory data indicate a rate of decontamination and disposal of PCB oils of 6.83% in 2016, of 1.76% in 2018, and of 0.09 % in 2017. (*fig. 21*).

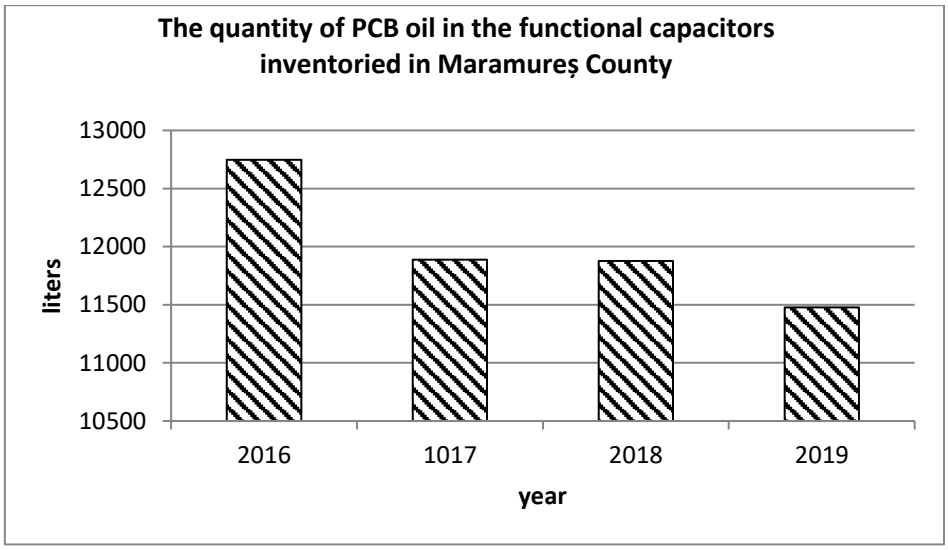

Fig. 20. The quantity of PCB oil in the functional capacitors inventoried for Maramures county in the period 2016-2018 [27-28]

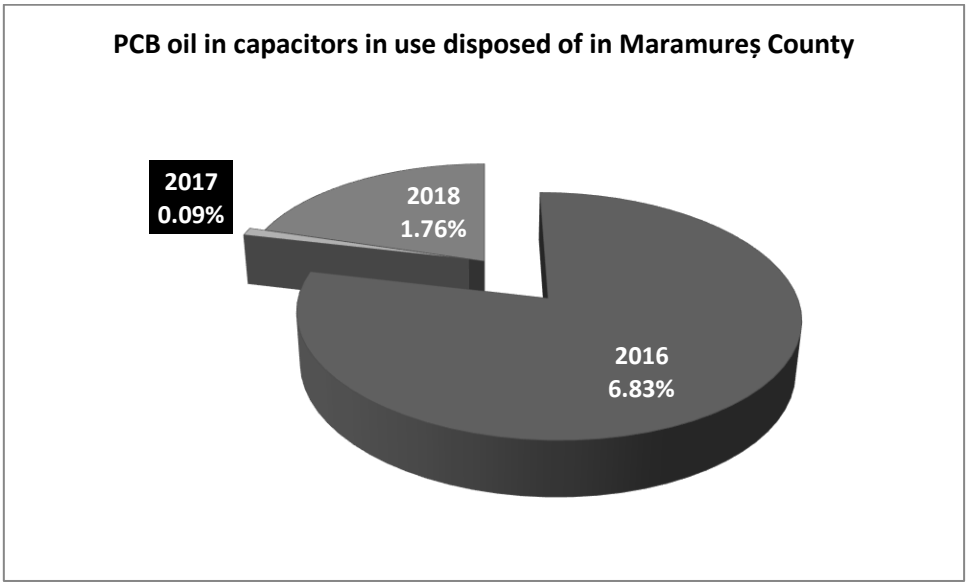

Fig. 21. PCB oil in capacitors in use decontaminated and disposed of in Maramures County in the period 2016-2018 [27]

In the period 2016-2018, the insufficient activity of decontamination and disposal of in use or waste electrical equipment with PCB was noticed both at the national and county level. This might be explained by the fact that there is only one authorized installation for decontamination of this kind of equipment with PCB [27].

3.3 Human health risks caused by PCBs

Like most organochlorine compounds, PCBs are persistent in the environment and accumulate in the food chain with affinity for adipose tissue (WHO, 2000). It accumulates mainly in the kidney, liver, adipose and epithelial cells [26].

The penetration of PCBs into the environment was done until their production was banned, in the form of emissions from industrial processes, or as leaks from the equipment or tanks with which these synthetic products were transported [5].

Many times, PCBs have accidentally ended up in various foods so that the population has been severely affected by them. One such incident occurred in 1968 in the Japanese city of Yusho. Because of the overheating of PCB oil-containing equipment that cooled rice bran oil, the PCB oil entered the edible oil and reached the population's food. Numerous symptoms have been registered such as increased discharge from the eye, lack of appetite, changes in nail color, hair loss, swelling of the limbs, nausea, vomiting, numbness of the limbs, and cutaneous symptoms [26].

Today, as the introduction of PCBs into equipment is not allowed, the danger of environmental contamination is the possible leakage of PCB-containing equipment waste or the decomposition of PCB-containing waste that has been in non-compliant landfills for many years [5].

Exposure of the population to PCBs can be achieved by ingestion with food or liquids; by inhalation or dermal contact. Also important are the dose, the duration of contact between the PCB and living organisms [5].

Studies have shown that air is the main pathway for the spread and dispersion of PCBs in the environment [3].

According to the study published by the WHO in 2003, the exposure of the population to PCBs can be followed by the appearance of many diseases, some of which are irreversible. Of these can be listed as follows [3-4]:

- different forms of cancer, including: cancer of the digestive system, cancer of the liver or melanoma etc
- deficiencies of the reproductive system
- developmental delay
- neurological effects
- immunological changes
- dermatological changes, including chloracnea, disorders of skin pigmentation, nails, gums; nail deformities, drowsiness, headaches and a sore throat

The effects that appear differ from individual to individual depending on the degree of exposure but also on the physical and mental characteristics of each individual.

Even the threshold limit values (TLV's) are not fixed by legislation, however there are some recommendations made in some states such as [4]:

United Kingdom Health and Safety Executive who set the following limits based on chlorine content [4]:

- for 42% chlorine content: long term exposure: l mg/m^3
- for 54% chlorine content: long term exposure: 0.5 mg/m^3

Germany which established through the former Federal Health Office of Germany recommended the following [4]):

- Tolerable Daily Intake (TDI): 1 mg per kg body weight per day
- if level exceeds 3000 mg per m^3 of air - Action should be taken
- level below 30 mg per m^3 of air should be kept as target

4. CONCLUSIONS

PCBs are part of the category of persistent organic compounds with a high capacity for bioaccumulation and significant damage to environmental factors and human health [1], [5]. These compounds have been used over time, due to their good dielectric properties, in various electrical equipment such as capacitors and transformers. Given the fact that there is a program for the gradual elimination of electrical equipment with PCB content that must be completed by 2025, Romania has developed a national inventory of equipment with PCB content that aims to monitor and ensure consistent management and efficient disposal of these categories of equipment and waste equipment.

The results obtained from the statistical processing and interpretation of the data provided by the national inventory of equipment and waste equipment containing PCBs reveal that in Romania the process of disposal is slow and that there are still large stocks of equipment containing PCBs that must be decontaminated and disposed of. By the end of 2018, the rate of decontamination and disposal of this equipment and the quantities of oils with PCBs contained was below 25%. In general, it is observed that the inventoried stocks decreased from 2016 to 2018 except for the waste transformers category which is registered in 2017 with 9 pieces more than the number of equipment registered in 2016 and with 2 more than the one registered in 2018.

Currently, there is no national or county inventory of equipment containing fluids with 0.005% to 0.05% PCB reported to the fluid weight [27].

In Maramureș County, there are no waste electrical equipment with PCB content, but only capacitors in use in the inventory. By the end of 2019, the rate of decontamination and disposal was below 15% [27-28].

The relatively slow pace of decontamination and disposal of electrical equipment, capacitors and transformers in Romania can be attributed to the fact that currently there is only one economic operator authorized to carry out the decontamination of equipment containing PCB/PCT. The oil extracted from this equipment is removed by incineration [27].

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