

#### **DIRECTORATE-GENERAL FOR INTERNAL POLICIES**

## POLICY DEPARTMENT CITIZENS' RIGHTS AND CONSTITUTIONAL AFFAIRS



EN

**Constitutional Affairs** 

Justice, Freedom and Security

**Gender Equality** 

**Legal and Parliamentary Affairs** 

**Petitions** 

Lindane (persistent organic pollutant) in the EU

STUDY FOR THE PETI COMMITTEE





#### DIRECTORATE GENERAL FOR INTERNAL POLICIES

### POLICY DEPARTMENT C: CITIZENS' RIGHTS AND CONSTITUTIONAL AFFAIRS

#### **PETITIONS**

# Lindane (persistent organic pollutant) in the EU.

#### **STUDY**

#### **Abstract**

This study was commissioned by the European Parliament's Policy Department for Citizens' Rights and Constitutional Affairs at the request of the Committee on Petitions (PETI). Lindane was extensively produced in the EU until the 1990s and used as a broad spectrum insecticide until 2008. The use and production of lindane is now banned in most countries around the world. However, it unfortunately continues to make itself known. Its persistence, bioacumulative and toxic properties, spillages from former production sites and the illegal dumping of HCH-waste, have given rise to serious concerns as understanding grows about the ability of HCH-polluted-spots to widely disperse HCH pollution into surface and groundwater.

This report presents an updated mapping of the lindane production plants and HCH-waste dumping sites in the EU. Potential remediation techniques, including laboratory and field experiences, are also provided with a selection of best practices regarding the restoration of contaminated sites and the participation of stakeholders. The information on lindane from official websites is also analysed.

PE 571.398 EN

#### **ABOUT THE PUBLICATION**

This research paper was requested by the European Parliament's Committee on Department for Citizens' Rights and Constitutional Affairs and commissioned, overseen and published by the Policy Department for Department for Citizens' Rights and Constitutional Affairs.

Policy departments provide independent expertise, both in-house and externally, to support European Parliament committees and other parliamentary bodies in shaping legislation and exercising democratic scrutiny over EU external and internal policies.

To contact the Policy Department for Department for Citizens' Rights and Constitutional Affairs or to subscribe to its newsletter please write to:

Poldep-citizens@ep.europa.eu

#### **Research Administrator Responsible**

Martina Schonard

Policy Department C: Citizen's Rights and Constitutional Affairs

European Parliament B-1047 Brussels

E-mail: Poldep-citizens@ep.europa.eu

#### **AUTHORS**

ERA-Consult Madrid, is a consultancy founded in 2001, dedicated to the environmental risk assessment of chemicals, specialized in aspects related to the implementation of European legislation.

Milagros Vega, Dolores Romano, Elina Uotila

#### LINGUISTIC VERSIONS

Original: EN

Manuscript completed in November 2016 © European Union, 2016

This document is available on the internet at: <a href="http://www.europarl.europa.eu/supporting-analyses">http://www.europarl.europa.eu/supporting-analyses</a>

#### DISCLAIMER

The opinions expressed in this document are the sole responsibility of the author and do not necessarily represent the official position of the European Parliament.

Reproduction and translation for non-commercial purposes are authorised, provided the source is acknowledged and the publisher is given prior notice and sent a copy.

#### **CONTENTS**

LIST C	F A	BBREVIATIONS	6
LIST C	F T	ABLES	8
LIST C	F FI	GURES	9
EXECU	TIV	E SUMMARY	10
1. LIN	<b>IDA</b>	NE: GENERAL INFORMATION	12
1.1.	Id	entity of the substance	12
1.2.	Ma	anufacture and uses	14
1.2	.1.	Manufacture	14
1.2	.2.	Uses	15
1.3.	Pr	operties of concern	15
1.3	.1.	Environmental distribution	15
1.3	.2.	Persistence (P)	15
1.3	.3.	Bioaccumulation (B)	16
1.3	.4.	Toxicity and Ecotoxicity (T)	16
1.3	.5.	Long-range environmental transport: transboundary movement	16
1.4.	Re	egulatory status of lindane in the EU	17
1.4	.1.	Legislation on levels of lindane in soils	17
1.4	.2.	Legislation on levels of lindane in water	19
2. TH	E LE	GACY OF LINDANE IN THE EU	22
2.1.	Αι	ıstria	24
2.2.	Βι	ılgaria	24
2.3.	Cr	oatia	24
2.4.	Cz	ech Republic	24
2.5.	De	enmark	26
2.6.	Fr	ance	26
2.7.	Ge	ermany	27
2.8.	Нι	ıngary	33
2.9.	Ita	aly	34
2.10.	La	tvia	35
2.11.	Po	land	35
2.12.	Ro	omania	36
2.13.	SI	ovakia	37

2.14	4.	Spain	38
2.15	5.	The Netherlands	43
2.16	6.	United Kingdom	45
3.	CON	IFINEMENT, TREATMENT AND DE-CONTAMINATION OPTIONS	47
3.1.	,	Confinement	48
3.2.	•	Combustion	48
:	3.2.1	L. Dedicated incinerators	48
	3.2.2	2. Cement kilns	49
3.3.		Physico-chemical treatment methods for waste, soil and water ediation and decontamination.	49
:	3.3.1	1. Base Catalysed Dechlorination (BCD) (Waste treatment)	50
:	3.3.2	2. Gas-Phase Chemical Reduction (GPCR) (Waste treatment)	50
;	3.3.3	<ol> <li>Non-base mediated dechlorination processes (Copper Catalysed dehalogenation; Fly Ash Catalysed Destruction (Hagenmaier Process); Sodium Reduction) (Waste treatment)</li> </ol>	51
;	3.3.4	1. Plasma Arc (Waste treatment)	51
:	3.3.5	5. Thermal desorption (Soil treatment)	52
:	3.3.6	5. Solvent extraction (Soil treatment)	53
:	3.3.7	7. Remediation by nanoparticles (Soil and water treatment)	54
:	3.3.8	3. Sorption by activated carbon (Water treatment)	54
;	3.3.9	9. Super Critical Water Oxidation (SCWO) (Water treatment)	55
:	3.3.1	10. Photocatalysis (Water treatment)	56
:	3.3.1	11. Biocatalytic dechorination (Water treatment)	56
:	3.3.1	12. In situ chemical oxidation (Soil and groundwater treatment)	57
3.4.	•	Biological methods: soil and water bioremediation	58
:	3.4.1	I. Microbial degradation	58
:	3.4.2	2. Biosorption microbes	61
	3.4.3	B. Phytoremediation	62
3.5.	•	Recycling activities	64
<b>4</b> .	BES	T PRACTICES	<b>65</b>
<b>4.1</b> .		Transparency: Construction of the Argalario safety landfill in the que Country (Spain)	e 66
4.2.		Stakeholder participation and Technical Centre of Coordination biñánigo)	66
4.3.	•	Stakeholder participation: Spanish PNA	67
4.4.		Factory decontamination: Hamburg Moorfleet site.	68

4.5.	Underground water monitoring: Bitterfeld-Wolfen	70
4.6.	HCH Polluted sites identification: Twente, Netherlands	72
5. INF	ORMATION ON LINDANE	73
6. REF	ERENCES	76
ANNEX	I. QUESTIONNAIRE ANSWERS	90

#### LIST OF ABBREVIATIONS

- **AC** Activated Carbon
- **BC** Basque Country
- **BCD** Base Catalysed Dechlorination
  - **CH** Switzerland
- **CMD** Copper Mediated Destruction
  - **CZ** Czchek Republic
- **DDT** Dichloro Diphenyl Trichloroethane
  - **DK** Denmark
- **DNAPL** Dense Non-Aqueous Phase Liquid
  - **ES** Spain
  - **EU** European Union
  - **FR** France
  - **GPRC** Gas-Phase Chemical Reduction
    - **HCH** Hexachlorocyclohexane
      - **HU** Hungary
  - ISCO In Situ Chemical Oxidation
- L(E)C50 Lethal Effective Concentration that produces 50% of lethality
  - **LV** Latvia
  - NCG National Coordination Group
  - **NIP** National Implementation Plan
    - **NL** The Netherlands
  - **NOEC** No Observed Effect Concentration
    - **OC** Organochlorine compounds

**PCB** Polychlorinated Biphenyls

**PCDD/PCDF** Polychlorinated dibenzodioxins/Polychlorinated dibenzofurans

**POP** Persistent Organis Pollutant (Stockholm Convention)

**PPP** Plant Protection Products

**RO** Romania

**SCWO** Super Critical Oxidation

**SVs** Soil Screening Values

**STP** Sewage Treatment Plant

**TCB** Trichlorobenzene

**TEQ** Toxic Equivalents

#### **LIST OF TABLES**

Chemical identity of lindane	13
FABLE 2.         Physical-chemical properties of lindane	14
TABLE 3.         National regulatory system for soil protection and SVs for lindane	18
TABLE 4.	
Overall quality standards for $\Sigma$ HCHs ( $\alpha$ -, $\beta$ -, $\delta$ -, $\epsilon$ - , $\gamma$ -HCH) (EC, 2005).	19
<b>FABLE 5</b> . Specific quality standards for lindane (γ-HCH) (EC, 2005).	21
FABLE 6.         Specific quality standards for HCHs except lindane	21
TABLE 7.         HCH waste production (tonnes) in Czech Republic	26
TABLE 8. HCH waste production (tonnes) in France.	27
TABLE 9.         HCH waste production (tonnes) in Germany.	31
ΓABLE 10.	
HCH waste production (tonnes) in Hungary.	33
TABLE 11. HCH waste production (tonnes) in Italy.	34
TABLE 12. HCH waste production (tonnes) in Poland.	36
TABLE 13. HCH waste production (tonnes) in Romania.	37
TABLE 14. HCH waste production (tonnes) in Slovakia.	37
TABLE 15. HCH waste production (tonnes) in Spain	43
TABLE 16.         HCH waste production (tonnes) in The Netherlands.	45
FABLE 17.         Examples of bacteria capable of degrading lindane and other HCH-isomers.	59
TABLE 18.         Lindane biosorption capacity of different adsorbents	62
FABLE 19.         Information to citizens from different authorities and organizations	73
FABLE 20.         Websites with information on chemicals	74

#### **LIST OF FIGURES**

FIGURE 1. Molecular structure of alpha, beta, gamma (lindane), delta and epsilon- HCH isomers	13
FIGURE 2.  Identified production and contaminated sites + countries with production but no information on the sites.	46
FIGURE 3. Schematic representation of the National Coordination Group on POPsination Group on POPs.	68
FIGURE 4. Underground scheme of the securing measures	70

#### **EXECUTIVE SUMMARY**

The objective of this report is to make a diagnosis of the situation in the European Union in relation to the current status of sites that are potentially contaminated with lindane and to get information on field restoration experiences. With this objective the following information has been compiled:

- The location of former lindane production plants;
- Identified polluted sites;
- Field experiences regarding the restoration of lindane-polluted sites; and
- State of the art research and laboratory techniques for the degradation of lindane.

For the elaboration of this report, more than one hundred questionnaires were submitted to different actors that were considered relevant at a national level. This included recent contact people and delegates of the Stockholm Convention<sup>1</sup>, representatives from the Spanish Autonomous Governments (3), academia (1), NGOs (6) and industry-consultancies working on the remediation of sites contaminated with POPs (3). The answers received are included in Annex I. This information as well as a review of an extensive scientific bibliography have been considered for the elaboration of this document.

#### The document provides,

- an updated picture of the European sites potentially contaminated with lindane and/or HCH-waste due to the presence of a production plant or a known illegal dumping and,
- a review of the laboratory techniques for lindane degradation and removal as well as field restoration experiences from lindane-polluted sites (soil, surface and groundwater),
- an analysis of the level of information on lindane from official websites.

General information on lindane and HCH isomers can be found in chapter 1. The identity of the substance can be found in section 1.1. Lindane is the common name for the gamma isomer of 1,2,3,4,5,6-hexachlorocyclohexane (HCH). Lindane and technical-HCH were produced in several European countries from the 1950s to the 1970s or 1990s. For each tonne of lindane obtained, approximately 6-10 tonnes of other waste HCH-isomers were generated. This very low production efficiency in the production of lindane resulted in high amounts of HCHs-waste (section 1.2). Because of its properties of high concern (carcinogenic, persistent, bioaccumulative and endocrine disrupting properties and evidence of long-range transport) technical-HCH and lindane became heavily scrutinised substances from the 1970s onwards (section 1.3). The current EU regulatory status is presented in section 1.4.

The low efficiency in the production of lindane has resulted in huge amount of wastes which produce the extensive contamination of soils, water and groundwater with toxic, persistent and bioaccumulative substances such as HCH isomers, chlorobencenes, and dioxins (chapter 2). In order to receive updated information on potential HCH-contaminated sites at EU level, a questionnaire was sent to the EU Competent Authorities on POPs, NGOs, academia and consultancies for requesting information. Answers to the questionnaire are included in Annex I. Lindane and HCH-polluted sites have not been fully identified in all Member States. As chemical production plants are often situated near rivers, river floods

<sup>&</sup>lt;sup>1</sup> 25 EU countries (no contact information regarding Greece, Slovenia and Luxembourg) and 14 NON-EU countries.

have contributed to the diffuse mobilization of contaminants from former production sites' spillages. Additionally, the illegal dumping of high amounts of waste is today causing concern because the many HCH-polluted-spots are located near rivers and therefore, are generating wide dispersive and extensive pollution via surface and groundwater (i.e. from the Sabiñánigo and Vitoria sites to the Ebro river, and from Bitterfeld-Wolfen site to the Elbe river).

A number of methods have been developed for the treatment and management of waste and for the removal of lindane from soil and water (chapter 3). Conventional methods include the excavation of contaminated soil and its containment in dedicated landfills, the confinement of contaminated groundwater or soil in order to contain it within a site, or pumpand-treat methods for groundwater (section 3.1). However, these methods are very expensive and neither disposing the substance in a landfill or confinement destroy or remove the contaminants from the soil matrix. Therefore, they are not considered as sustainable definitive remediation methods. Another traditional method is the combustion of the contaminated waste (section 3.2). However, the setbacks of combustion are its low-cost effectivity and its potential to produce even more toxic compounds such as dioxins and furans. Physical treatment methods separate the contaminants from water, soil and waste matrix by using physical differences between the matrix and contaminant. Physico-chemical treatment methods destroy, fix or concentrate the contaminants by using chemical reactions (section 3.3) and are the most frequently considered. Field experiences with different methods are also provided. Biological treatment methods (section 3.4) of contaminated soils and waters involve the use of micro-organisms or vegetation. Micro-organisms and plants can destroy contaminants or transform them to less hazardous chemicals, as well as extract and accumulate them. The advantage of biological methods is that they are environmentallysound low-cost methods and they can be used in situ. However, the efficiency of these methods in field conditions may still be quite limited as there are many factors that affect

Waste dumping, landfills or contaminated soils are usually widespread and disseminated via surface waters and/or groundwater over long time-scales and large distances. Complex interactions such as multiple pollutants with high persistence and a high potential to disseminate to different environmental compartments also make the issue more complicated. That is the reason why multidisciplinary and collaborative approaches result in better management and decision-making tools to improve the remediation of lindane and HCH-waste polluted sites (chapter 4). Several cases have been collected as examples of transparency and stakeholder participation (sections 4.1, 4.2 and 4.3) and experiences of field remediation are documented including demolition activities and strategies for buildings that are also probably highly contaminated with PCDD/PCDF and PCB (sections 4.4, 4.5 and 4.6). Sites where lindane waste has been deposited require continuous long-term monitoring, leachate pump and treatment as well as maintenance activities for decades.

Chapter 5 is aimed at raising the level of **information provided on official websites**. It seems that, as a general approach, general information on chemicals is provided by all Member States. However, information on lindane is only provided by those regional governments with specific mega polluted sites.

#### Acknowledgments

We want to express our thanks to those people who have provided information and specially to John Vijgen for his help and contribution to this document.

#### 1. THE LEGACY OF LINDANE: GENERAL INFORMATION

#### **KEY FINDINGS**

- Lindane is the gamma isomer of 1,2,3,4,5,6-hexachlorocyclohexane (HCH). Technical HCH is a mixture of five different isomers, including the gamma isomer, of HCH. They belong to the organochlorine pesticides group. Technical HCH has been a very inefficient pesticide, due to the fact that only the gamma isomer has insecticidal properties and the "inefficient" other isomers have been spread all over the countries during its application
- Lindane was produced in several European countries from the 1950s to the 1970s or 1990s. For each tonne of lindane obtained, approximately 6-10 tonnes of other waste HCH-isomers are generated.
- Lindane was used as a broad-spectrum insecticide for many agricultural and nonagricultural purposes. The total use in Europe was hundreds of thousands of tonnes from 1950 to 2000.
- In the EU, since 2008, all uses of lindane are banned. In 2009, lindane and two other HCH-isomers were included in the Stockholm Convention on Persistent Organic Pollutants (POPs) in order to achieve the global elimination of these substances.
- Lindane and other HCH-isomers are persistent in the environment, they bioaccumulate in living organisms and are toxic to human health and the environment. Furthermore, there is evidence of their long-range transport.
- There are currently no EU level rules regarding lindane contaminated soils, but some Member States have their own legislation for soil protection, including limit values for lindane.

#### 1.1. Identity of the substance

Lindane is the common name for the gamma isomer of 1,2,3,4,5,6-hexachlorocyclohexane (HCH). The molecular structure of HCH consists of a six-carbon ring with one chlorine and one hydrogen attached to each carbon. The so-called technical HCH also contains the other isomers of HCH, which differ only by the chlorine atoms orientation (axial or equatorial positions) around the cyclohexane ring (Figure 1). The five principal isomers are present in the mixture in the following proportions: alpha-hexachlorocyclohexane (53%–70%) in two enantiomeric forms ((+) alpha-HCH and (-) alpha-HCH), beta-hexachlorocyclohexane (3%–14%), gamma-hexachlorocyclohexane (11%–18%), delta-hexachlorocyclohexane (6%–10%) and epsilon-hexachlorocyclohexane (3%–5%). The gamma isomer is the only isomer showing strong insecticidal properties. The purity of lindane is normally more than 99% gamma-HCH.

Lindane belongs to the chemical family of chlorinated hydrocarbons and to the organochlorine (OC) pesticides group. Other pesticides in this group include e.g. DDT, aldrin, dieldrin, endrin, heptachlor, chlordane and endosulfan. OC pesticides are some of the oldest pesticides used, but due to their high persistency and toxicity, many of these previously widely used pesticides, including lindane, have been banned.

The main physical and chemical properties of lindane are shown in Table 1.

Table 1. Chemical identity of lindane

Common name	Lindane
Chemical name	γ-1,2,3,4,5,6-hexachlorocyclohexane
EC-number	200-401-2
CAS-number	58-89-9
Chemical formula	C <sub>6</sub> H <sub>6</sub> Cl <sub>6</sub>
Molecular weight	290.83

Figure 1. Molecular structure of alpha, beta, gamma (lindane), delta and epsilon-HCH isomers

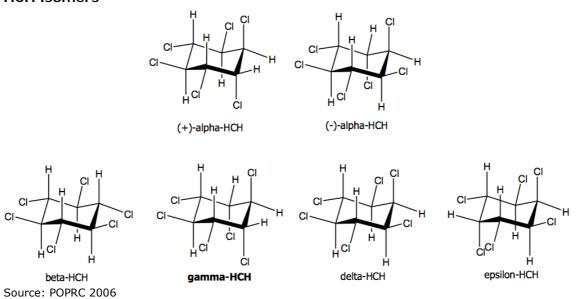


Table 2. Physical-chemical properties of lindane

Property	Value
Colour/form	Colourless to white crystalline powder/solid
Boiling point	323.4 °C
Melting point	112.5 °C
Water solubility	7.3 mg/L at 25 °C
Vapour pressure	4.2x10-5 mmHg at 20°C 4.4 x 10-3 Pa at 24 °C
Henry's Law constant	1.48-5.14 x 10-6 atm m3/mol at 25°C
Partition coefficient (log Kow)	3.51-3.72
Soil sorption coefficient (Koc)	1080.9 871-1671

source: HSBD 2016

#### 1.2. Manufacture and uses

#### 1.2.1. Manufacture

Lindane was produced in many European countries, such as the Czech Republic, Spain, France, Germany, the United Kingdom, Italy, Romania and Poland, mainly from the 1950s to the 1970s or 1990s. In Romania the production continued until 2006. The production of these substances has also taken place in other countries including Argentina, Azerbaijan, Brazil, China, Ghana, India, Japan, Russia and the United States (Vijgen, 2006). Currently there is believed to be only one operating plant worldwide, located in India, that is still producing lindane for pharmaceutical purposes (Vijgen et al. 2011).

The starting material for manufacturing lindane is technical-HCH. Technical-HCH is manufactured by the photochlorination of benzene, which yields a mixture of five main isomers. Gamma-HCH is extracted and purified from this mixture of isomers using fractional crystallization to produce 99% pure lindane. The production of lindane is inefficient as for each tonne of lindane (gamma isomer) obtained, approximately 6-10 tonnes of other waste isomers are also obtained (Vijgen, 2006).

According to the International HCH & Pesticide Association (Vijgen, 2006), attempts have been made to develop methods to destruct and re-use the other HCH isomers formed during the manufacture of lindane. However, most of these methods have been rejected over the years and, consequently, most of the waste products have been dumped over the last 50 years (Vijgen, 2006). IHPA (Vijgen, 2006) has estimated that the global amount of waste

HCH-isomers still present may be in the range of 1.7 - 4.8 million tonnes. In some European countries that previously manufactured lindane and technical-HCH (e.g. France, Germany and Spain), the amount of HCH-waste is estimated to be hundreds of thousands of tonnes (Vijgen, 2006).

#### 1.2.2. Uses

Lindane and technical-HCH have been used as broad-spectrum insecticides, which act through contact, for both agricultural and non-agricultural purposes. Their uses have included seed and soil treatment, foliar applications, tree and wood treatment and treatment against ectoparasites in both veterinary and human applications (WHO, 1991).

The International HCH & Pesticide Association (Vijgen, 2006) estimated that global lindane use was around 600,000 tonnes during the period from 1950 to 2000. Most of that, approximately 450,000 tonnes globally and 290,000 tonnes in Europe, was used for agricultural purposes (Vijgen 2006). In another study, Breivik et al. (1999) estimated that around 400,000 tonnes of technical HCH and 81,000 tonnes of lindane were used in Europe from 1970 to 1996. In Europe, the top 10 countries with the highest lindane usage between 1950 and 2000, representing 96% of the total usage in Europe, were: Czechoslovakia, Germany, Italy, France, Hungary, Spain, Russia, Ukraine, Yugoslavia and Greece (Vijgen, 2006).

#### 1.3. Properties of concern

Alpha, beta and gamma-HCH (lindane) have been included in the Stockholm Convention on Persistent Organic Pollutants (POPs) as they fulfil the criteria set out in the Annex D of the Stockholm Convention for being persistent, bioaccumulative, having harmful impacts on human health or on the environment and having potential for long range transport. In this chapter, information on these properties of lindane is summarised. The other principal HCH-isomers have similar properties.

#### 1.3.1. Environmental distribution

Once released into the environment, lindane can disseminate to all environmental compartments. Compared to other organochlorine pesticides (e.g. DDT), lindane and other HCH isomers are generally more water-soluble and volatile, which explains why they are so ubiquitous. Based on the Henry's Law constant<sup>2</sup>, evaporation from water and moist soil is the most important process in the environmental distribution of lindane (USEPA, 2006).

Lindane shows a strong tendency to be adsorbed into organic material (Koc 871-1671) and therefore the mobility of the substance is expected to be very low in soils with a high content of organic material, and higher in soils with little organic matter. The diffusion of lindane is strongly influenced by the water content of the soil and by temperature (see review by Phillips eta al. 2005).

Due to the low water solubility (7.3 mg/L) and high adsorption potential, lindane is expected to partition into sediment and to bind into solid particulates in the water column in aquatic environments.

#### 1.3.2. Persistence (P)

Lindane is stable to light. Since lindane does not contain chromophores that absorb light, direct photolysis either in air, water or soil is not expected to occur.

Hydrolysis is not considered an important degradation process for lindane in aquatic environments under neutral pH conditions. Different estimated and calculated half-life values

\_

<sup>&</sup>lt;sup>2</sup> The Henry's law constant for a substance is a measure of its equilibrium between a solution phase and the vapour phase. As such it is a measure of the potential for a substance to be lost by evaporation.

\_\_\_\_\_

for lindane have been reported to be: 11 years at pH 8 and 20°C in seawater; 42 years at pH 7.6 and 5°C in Lake Huron, and 110 years in the Arctic Ocean at pH 8 and 0°C (USEPA, 2006).

Lindane degrades very slowly by microbial action with a calculated half-life in soil of 980 days under laboratory aerobic conditions. Degradation takes place faster under anaerobic conditions than in the presence of oxygen. Possible degradation products are pentachlorocyclohexene, 1,2,4-trichlorobenzene, and 1,2,3-trichlorobenzene (USEPA, 2006).

According to these characteristics, lindane and its isomers are considered persistent substances.

#### 1.3.3. Bioaccumulation (B)

Lindane can bioaccumulate easily in the food chain due to its high lipid solubility and can bioconcentrate rapidly in microorganisms, invertebrates, fish, birds and mammals. Bioconcentration factors (BCF) within aquatic species vary considerably, with experimental data revealing BCF of 3-36 (Berny, 2002); 43-4220 on a wet weight basis, and a mean BCF of 11,000 on a lipid basis (Geyer et al., 1997); and also 1200-2100 (Oliver et al., 1985).

The bioaccumulation of lindane has been observed for most taxonomic groups, from plants and algae to vertebrates. Concentrations in marine mammals are found at equivalent or even higher levels than some of the more hydrophobic contaminants such as polychlorinated biphenyls (PCBs) and DDT (ATSDR, 2005). Human exposure to lindane, particularly in pregnant women and children, is a concern heightened by the ongoing presence of HCH isomers in human tissues and breast milk (AMAP, 2002).

#### 1.3.4. Toxicity and Ecotoxicity (T)

The International Agency for Research on Cancer (IARC) has classified lindane as carcinogenic to humans (Group 1). There is sufficient evidence in humans for the carcinogenicity of lindane for non-Hodgkin lymphoma (NHL) (IARC, 2016).

Lindane is the most acutely toxic HCH isomer affecting the central nervous and endocrine systems. In humans, effects from acute exposure at high concentrations may range from mild skin irritation to dizziness, headaches, diarrhoea, nausea, vomiting, and even convulsions and death (CEC, 2005). Respiratory, cardiovascular, hematological, hepatic and endocrine effects have also been reported for humans, following acute or chronic lindane inhalation. Haematological alterations like leukopenia, leukocytosis, granulocytopenia, granulocytosis, eosinophilia, monocytosis, and thrombocytopenia, have been reported, following chronic human occupational exposure to gamma- HCH at production facilities (ATSDR, 2005).

Lindane is highly toxic to aquatic organisms. The acute (L(E)C50) and chronic (NOEC) toxicity values for many fish and aquatic invertebrates are in the level of micrograms/L (see studies referred to e.g. in HSBD 2006 and the EQS data sheet EC, 2005). The substance shows moderate acute toxicity to birds and mammals, and long term effects on reproduction and development have been observed in these animals (USEPA 2006). Lindane is also very toxic to bees (USEPA 2006). Furthermore, endocrine disrupting properties have been detected in many animals, e.g. birds, frogs and mammals (USEPA 2006), which is a cause for very high concern for human health and the environment.

#### 1.3.5. Long-range environmental transport: transboundary movement

High concentrations of gamma-HCH in air occurred in France, Portugal, Spain, the Netherlands and Belgium. These can be explained by the high emission densities of lindane in these countries. Relatively high air concentrations were also found in Germany, Italy, Switzerland and Luxembourg, despite the lower lindane emission densities in these countries. These elevated air concentrations were probably explained by atmospheric transport from

the former high-density emission European countries (Shatalov and Malanichev, 2000; Shatalov et al., 2000).

Lindane is very prevalent in the marine environment and soils, and its atmospheric long range transport potential has been demonstrated for the European Union, (WHO/Europe, 2003) especially by the European Monitoring and Evaluation Program.

Many studies have reported HCH residues, particularly alpha and gamma isomers throughout North America, the Arctic, Southern Asia, the Western Pacific, and Antarctica. HCH isomers, including lindane, are the most abundant and persistent organochlorine insecticide contaminants in the Arctic, and their presence in the Arctic and Antarctic, where technical HCH and lindane have not been used, is evidence of their long-range transport. HCH isomers, including lindane, are subject to "global distillation" in which warm climates at lower latitudes favour evaporation into the atmosphere where the chemicals can be carried to higher latitudes. At high latitudes, cold temperatures favour atmospheric deposition (Walker et al., 1999).

#### 1.4. Regulatory status of lindane in the EU

Because of its carcinogenic, persistent, bioaccumulative and endocrine disrupting properties (WHO 1991; ATSDR 1998; ATSDR 2005; UNEP 2005a, b; IARC, 2016), technical HCH and lindane became heavily scrutinised substances from the 1970s onwards. Many countries banned or restricted, first, the use of technical HCH in the 1970s, and then the use of lindane in the 1980s and 1990s (Hauzenberger et al., 2004). Furthermore, various bilateral and multilateral international agreements and treaties have addressed the substances, e.g. the Rotterdam Convention, the Aarhus Protocol on Persistent Organic Pollutants, the OSPAR Commission for the Protection of the Marine Environment of the Northeast Atlantic, the Great Lakes Binational Toxics Strategy between the United States and Canada, and a "North American Regional Action Plan on Lindane and Other Hexachlorocyclohexane Isomers" under the Commission for Environmental Cooperation between Canada, the United States and Mexico.

In 2009, lindane, alpha-HCH and beta-HCH were included in Annex A of the Stockholm Convention on Persistent Organic Pollutants (POPs) in order to achieve the global elimination of these substances. This meant that the production and use of these substances was banned from August 2010 onwards in all the countries that are members of the Stockholm Convention, with the possibility of a specific exemption for the use of lindane as a human health pharmaceutical for the control of head lice and scabies as a second-line treatment. This exemption has been applied in some countries.

In the EU, the use of plant protection products containing HCH with less than 99.0% of the gamma isomer was prohibited in 1979 by the Directive 79/117/EEC. In 2004, the Regulation (EC) No. 850/2004 banned all uses of lindane with certain derogations that expired by the end of 2007. Thus, since 2008, the use of these substances is not allowed in the EU.

#### 1.4.1. Legislation on levels of lindane in soils

Soil is not subject to a comprehensive and coherent set of rules in the European Union. The Commission in May 2014 decided to withdraw the proposal for a Soil Framework Directive, included in the Seventh Environment Action Programme. This Programme provided that by 2020 land is managed sustainably in the Union, that soil is adequately protected and the that the remediation of contaminated sites is well underway. It also commits the EU and its Member States to increase efforts to reduce soil erosion, increase soil organic matter content and to remediate contaminated sites (EC, 2016a).

\_\_\_\_\_

At the moment, only a few EU Member States have specific legislation on soil protection. It is based on Soil Screening Values (SVs), which are generic quality standards that are used to regulate the management of contaminated land. The implications of exceeding the soil SVs vary according to national regulatory frameworks. They range from the need for further investigations to the need for remedial actions.

SVs adopted in European countries are often classified on the basis of their use and are widely variable. Drawbacks to this type of classification include the fact that the prescribed use of SVs is specific to each national regulatory framework and that they often include a complex system of rules and exemptions (e.g. the time when contamination was determined) and type of substances to which they apply (e.g. mobile and non mobile). Moreover, the use of SVs is currently changing in many countries without changes to the derivation methods used to determine SVs. As a general point, the classification of SVs is based on risk levels (negligible, intermediate and potentially unacceptable). Information on the how different national regulatory systems for soil protection are determined can be consulted in Carlon (2007).

In Table 3 those EU counties with national regulatory system for soil protection are presented along with their values for lindane. Additionally, values for total-HCHs and/or alpha-HCH and beta-HCH isomers are also included, when available.

Table 3. National regulatory system for soil protection and SVs for lindane

	Screening values for lindane			
	Threshold value (mg/kg-dw)	Lower value (mg/kg-dw)	Upper value (mg/kg-dw)	Groundwater (µg/L)
Austria	-	-	-	-
	-	-	-	2
Belgium	-	-	-	0.06 <sup>h</sup>
	-	-	-	0.2 <sup>i</sup>
Czech Republic	-	-	-	-
Denmark	-	-	-	-
Findland	0.01	0.2 <sup>f</sup>	<b>2</b> <sup>g</sup>	-
Europe	0.2	0.5	470	0.1-2
France	5 <sup>e</sup>	10 <sup>e</sup>	400e	0.1-2
Germany	-	-	-	-
	-	0.01 <sup>c</sup>	0.5 <sup>d</sup>	0.1
Italy	-	0.01 <sup>h</sup>	0.5 <sup>h</sup>	0.1 <sup>h</sup>
	-	0.01 <sup>i</sup>	0.5 <sup>i</sup>	0.1
Lithuania	-	-	0.02 <sup>e</sup>	-
Dalama	0.000005	0.0005	0.5	*
Poland	0.0025 <sup>h</sup>	0.25 <sup>h</sup>	2 <sup>h</sup>	*

	Screening values for lindane			
	Threshold value (mg/kg-dw)	Lower value (mg/kg-dw)	Upper value (mg/kg-dw)	Groundwater (µg/L)
	0.001 <sup>i</sup>	0.1 <sup>i</sup>	2 <sup>i</sup>	*
Slovakia	-	-	-	-
	0.01	0.1	1 <sup>h,i</sup>	*
Spain	0.01 <sup>h</sup>	0.01 <sup>h</sup>	0.01 <sup>h</sup>	*
	0.01 <sup>i</sup>	0.01 <sup>i</sup>	0.01 <sup>i</sup>	*
Sweden	-	-	-	-
	-	0.00005	-	-
The Netherlands	-	0.003 <sup>h</sup>	-	-
	-	0.009 <sup>i</sup>	-	-
	-	0.01 <sup>e</sup>	2 <sup>e</sup>	1 <sup>e</sup>

Source: Carlon, 2007.

c: residential/public green use; d: industrial/commercial use; e: total-HCHs; f: based on ecological risk; g: based on risk for human health; h: values for a-HCH; i: values for  $\beta$ -HCH; \* The threshold value for the protection of the ecosystem includes groundwater;

#### 1.4.2. Legislation on levels of lindane in water

The Water Framework Directive (WFD) 2000/60/CE seeks to progressively reduce emissions, discharges and losses of priority substances to waters. Priority hazardous substances are to be phased out completely within 20 years. Lindane is included in this list.

The WFD also establishes two types of environmental quality standards (EQS) for priority substances: annual average concentrations and maximum allowable concentrations. The former protects against long-term chronic pollution problems, and the latter short-term acute pollution. Member States are responsible for monitoring the concentrations of priority substances in surface waters. All HCH isomers are included in the list of priority substances (EC, 2005). EQS have been established for lindane and also for the sum of HCH isomers:

Table 4. Overall quality standards for **\SigmaHCHs** ( $\alpha$ -,  $\beta$ -,  $\delta$ -,  $\epsilon$ -,  $\gamma$ -HCH) (EC, 2005).

Ecosystem	Quality Standard (QS)	Quality Standard rounded values
QS inland surface waters	0.02 μg/l (10.8 μg/kg SPM dry wt)	0.02 μg/l (11 μg/kg SPM dry wt)
QS other surface waters covered by the WFD	0.002 μg/l (1.1 μg/kg SPM dry wt)	0.002 μg/l (1 μg/kg SPM dry wt)

Ecosystem	Quality Standard (QS)	Quality Standard rounded values
QS maximum acceptable concentration	0.04 μg/l	0.04 μg/l

SPM= Suspended particulate matter

Table 5. Specific quality standards for lindane (γ-HCH) (EC, 2005).

Protection Objective	Quality Standard
Pelagic community (freshwater)	0.02 μg/l (10.8 μg/kg SPM dry wt)
Pelagic community (saltwater)	0.002 μg/l (1.1 μg/kg SPM dry wt)
Benthic community (freshwater sediment)	2.4 μg/kg wet wt ( $\approx$ 10.3 μg/kg dry wt)
Benthic community (marine sediment)	0.24 μg/kg wet wt ( $\approx$ 1.1 μg/kg dry wt)
Predators (secondary poisoning)	33 μg/kg (tissue of prey, wet wt) corresponding concentration in water: 0.026 μg/l
Food uptake by man	61 μg/kg (seafood, wet wt); corresponding concentration in water 0.047 μg/l
Abstraction of water intended for human consumption (AWIHC)	< 1 µg/l
Water intended for human consumption (WIHC)	0.1 μg/l

Table 6. Specific quality standards for HCHs except lindane

Protection Objective #	Quality Standard
Pelagic community (freshwater)	0.1
Pelagic community (saltwater)	0.01
Benthic community	not required
Predators (secondary poisoning)	67 μg/kg (tissue of prey, wet wt) corresponding conc. in water: 0.042 μg/l
Food uptake by man	derivation of QS not possible but required according to trigger criteria
Abstraction of water intended for human consumption (AWIHC)	< 1 μg/l
Water intended for human consumption (WIHC)	0.1 μg/l

\_\_\_\_\_

#### 2. THE LEGACY OF LINDANE IN THE EU

#### **KEY FINDINGS**

- In almost all Member States where lindane production took place, the elimination and de-pollution of soils, surface water and groundwater is needed.
- Contamination in the production sites was not always the result of specific deposition activities, but mainly occured from spillages during daily routine operations. Normal long-term disposal operations of the factory's production should also be considered as a potential source of HCH pollution (i.e. Morfleet site in Hamburg).
- The production of lindane in the EU has resulted in the extensive contamination of soils, water and groundwater with toxic, persistent and bioaccumulative substances such as lindane, HCH isomers, chlorobenzenes, and dioxins.
- Lindane- and HCH-polluted sites have not been fully identified in all Member States.
- HCHs waste is usually in the scale of hundreds and thousands of tonnes and, therefore, represents a large contaminant reservoir.
- Hot-spots, with thousands, and often hundred thousands, of tonnes of lindane and HCH waste, are pending remediation activities in, at least, the following Member States: the Czech Republic, France, Germany, Hungary, Italy, Poland, Romania, Slovakia and Spain.
- Chemical production plants are often situated near rivers and river floods have contributed to the diffuse mobilization of contaminants (from Sabiñánigo and Vitoria sites to the Ebro river, Bitterfeld-Wolfen site to the Elbe river). Climate change and an increased number of floods will contribute to an intensified POPs discharge into rivers.

As it has been indicated (section 1.2.1), the efficiency of the production process of lindane is very low, resulting in a high volume of production waste containing several HCH isomers. Initially, this waste was considered inert and stored at production sites, dumped in landfills, quarries and even used for road fillings and as construction material. Waste water emissions, together with spillages from daily routine operations including spills from the production processes, leaks from transportation pipes, storage, the loading and unloading of chemicals and the interim storage of the HCH isomer waste, contributed to the pollution of and from production sites.

In order to have an overview of the legacy of lindane in EU Member States, information has been collected focusing on production sites, the amounts of HCH and lindane produced, waste generation and the management of environmental impacts. Where information has been available, the current situation of production sites, waste deposits and the contamination of different environments (soil, surface and groundwater) is also described.

Although the formulation of lindane into different commercial products took place in most EU Member States, this chapter focuses on the 14 EU Member States where lindane production took place because of waste generation, and the higher environmental impact of production compared with formulation.

#### Methodology

For the elaboration of this report, more than one hundred questionnaires were submitted to different actors considered relevant at a national level: recent contact people and delegates of the Stockholm convention<sup>3</sup>, representatives from the Spanish Autonomous Governments (3), Academia (1), NGOs (6) and consultancies working on the remediation of sites contaminated with POPs (3),

The responses have been received from:

Six Member State delegates

Ministry of the Environment of the Czech Republic
Danish Environmental Protection Agency
Ministry of Agriculture, Food and Environment of Spain
National Food Chain Safety Office of Hungary
Ministry of Environmental Protection and Regional Development of Latvia
Ministry of Environment, Water and Forests of Romania

• Three Spanish Autonomous Governments

Basque County: Secretary of Environmental Administration Xunta de Galicia Gobierno de Aragón

Six NGOs

Greenpeace Central and Eastern Europe,
Asociación Soriana para la Defensa y Estudio de la Naturaleza (ASDEN),
Green Cross,
Ecologistas en Acción,
Ekologistak Martxan,
International HCH and Pesticides Association (IHPA)

Three consultancies

Tauw bv,

Kruger A/S,

Martin Forter, Independent scientist for municipalities, residents and environmental organisations

One academia

Department of Isotope Biogeochemistry Helmholtz Centre for Environmental Research - UFZ

The information provided in the responses to the questionnaire, along with other available information, is summarised in the sections below. Responses received can be consulted in Annex I.

<sup>&</sup>lt;sup>3</sup> 25 EU countries (no contact information regarding Greece, Slovenia and Luxembourg) 14 NON-EU countries

#### 2.1. Austria

One company manufactured lindane in Austria until 1965. No information is available on the production quantities or waste management methods. There are no registered contaminated sites in Austria (Vijgen, 2006). UBA Austria is in the process of starting up investigations at the site of the former producer (Vijgen, personal communication).

#### 2.2. Bulgaria

Several sources indicate that manufacture of lindane took place in Bugaria (Vijgen, 2006; POPRC,2006), however, no data are available on sites, production periods or quantities. According to current knowledge lindane may have never have been produced in Bulgaria (Vijgen, personal Communication)

#### 2.3. Croatia

Four manufacturers produced a total amount of seven tonnes of lindane per year in Croatia (Vijgen, 2006). No further information is available.

#### 2.4. Czech Republic

34 sites contaminated by lindane have been identified in the Czech Republic, including those where remediation has been finished or is ongoing. According to information provided by the Ministry of Finance in cooperation with the Czech Environmental Inspecorates (Vytopilova, personal communication), each site is evaluated separately and managed "case-by-case" according to Czech guidelines and Czech methodology recommendations of the Ministry of the Environment (see Annex I).

Several polluted sites have been highlighted:

#### **Neratovice**

Spolana Neratovice, located at Neratovice, 25 km north of Prague on the Elbe River was the single lindane manufacturer in the Czech Republic. It produced about 3,300 tonnes of lindane (Beránek et al, 2006) and 61,680 tonnes of technical HCH between 1963 and 1972 (Vijge, 2006). Production ceased due to occurrence of chloracne during the production of Agent Orange. Waste of ballast isomers and chlorinated benzenes was deposited together with other industrial waste in the mine "Hájek" near the village of the same name located in the region of Karlovy Vary.

The remediation of the site began in 2005 and is still ongoing. Activities including the decontamination and demolition of two buildings, the excavation and treatment of surrounding soils, the treatment of chemicals stored closed to the main building, the dissembling and treatment of the process unit and final restoration of the site. Waste was treated on site by base catalysed dechlorination (Holoubek et al., 2011) (see section 3.3.1. for further information on this method).

The Spolana Neratovice factory is one of the best studied POP hot spots in the country. From March 2009 the programme MONET-Europe (MONnitoring NETwork) has measured hundreds of nanograms of HCH per filtering device in the ambient air in the vicinity of the factory (Holoubek et al., 2011).

#### Dumpsite at mine "Hájek" (Karlovy Vary)

One of the most serious environmental problems in the Czech Republic, but less known than Spolana Neratovice, is connected with the former production of lindane and technical HCH in the mine "Hájek" near the village of the same name (south-eastward from Ostrov in the region of Karlovy Vary). In the 1960s, the government authorities decided to deposit ballast isomers from the production of lindane and chlorinated benzenes in the "Hájek" mine in metal barrels, paper packages or freely embedded them. The estimated amount of chemicals placed in a dump like this is about 3,000 to 5,000 tonnes. Mine water flows eastward to Ostrovský creek, which supplies a system of fish ponds 1.5 kms away from the dump. Due to the high level of groundwater below the dump, solid particles, as well as dissolved chlorinated organic substances, are washed out to surface waters, with the possibility of these substances contaminating food chains. In 1999, works were carried out to prevent water infiltrating the site and to stop contaminated water flowing out of it. 12.1 ha of the site have been decontaminated (Beránek and Havel, 2006).

#### Klatovy-Luby - former store of pesticides

Another lindane hot spot in the Czech Republic is an old pesticide storage located in the centre of an inhabited area of Klatovy-Luby. Commercial buildings in Klatovy-Luby were used for the storage and formulation of pesticides from the 1960s to the beginning of the 1990s. Analyses of plaster of the building, soil and groundwater proved that are these areas are strongly contaminated wth DDT, lindane, fenson or atrazine, and oil products.

The case of the pesticide store in Klatovy-Luby is certainly not the only one in the Czech Republic. In the former Czechoslovakia, there were likely similar stores and preparation halls for pesticides in, more or less, each district (see Annex I). Contaminated plaster and parts of inside walls were used for a demonstration decontamination exercise using a non-combustion technology called copper mediated destruction (CMD) (Beránek and Havel, 2006).

According to the information provided by the environmental authority, stocks of obsolete pesticides were mainly disposed through high temperature incineration in the 1990s (Vytopilova, personal communication. See References).

Table 7. HCH waste production (tonnes) in Czech Republic

Location (company): period	HCH waste Production	Current situación
Neratovice, Melnik district (Spolana Neratovice): 1961 -1972	60,000 tonnes	The decontamination and remediation of the site started in 2005
Hájek, Karlovy Vary (Dump of mine "Hájek")	The estimated amount of chemicals, placed in a dump like this is about 3,000 to 5,000 tonnes. The dump has a volume of approx 7 million cubic metres	In 1999, the recovery works started. Recovery was completed in an area of 12.1 hectares
Luby, Klatovy (Klatovy-Luby - former store of pesticides: 1960s- 1990s	Lindane in obsolete stockpiles, 180 tonnes	Used for demonstration decontamination CMD technology

#### 2.5. Denmark

According to the information provided by the environmental authority (Gravesen, personal communication. See references), lindane has never been produced in Denmark and there is no awareness on any disposal or polluted site.

Lindane has been banned in Denmark since 1994. It is believed that obsolete lindane containing pesticides was disposed of in an incineration plant for hazardous waste.

#### 2.6. France

Nine manufacturers produced lindane in France between from the 1940s to the 1980s, with an overall production capacity of 1,800 t/year. HCH was deposited in seven sites. Part of the residues were burnt in 1986 and 500 tonnes moved to Northern France for destruction in the 1980s. About 260,000 tonnes of HCH production residues have been located in an area of about 35,400  $\text{m}^2$  (Vijge, 2006). Unfortunately, only information regarding one of the manufacturers is available.

#### Huningue, Haut-Rhin

Between 1947 and 1974, the company Chemicals Ugine Kuhlman (PCUK) in Huningue manufactured lindane, producing about 100,000 tonnes of HCH-waste. The plant was closed in 1976 and the buildings were demolished. HCH-waste and concrete loaded with HCH-waste were left in the basement of the site. Several thousand tonnes of HCH-waste are buried on the industrial site. However, the largest part of the waste produced by PCUK was stored in 11 empty gravel pits in Ober-und Unterelsass, France, as well as in Gouhenans (Forter, 2015).

About 4,000 m³ of gravel was excavated from the industrial site in 1972-73 and used on roads through the fields from Hagenthalle- Bas (FR) and Hagenthal-le-Haut (FR) to a Swiss community. The HCH-concrete in Hagenthal-le-Bas (FR) contained up to 750 g/kg of HCH.

From 1981 until 2012 a wastewater treatment plant operated on the Huningue site for Sandoz AG, hereafter for Novartis Basel (CH) and Huningue, Clariant Huningue (FR) and BASF Huningue (FR). In 2013, Novartis and Sita Remediation began remediation work on the site by removing the HCH-waste (Steih, 2012). Very slightly contaminated material is sorted directly on site (Steih 2016). Highly contaminated material is placed first into containers and moderately contaminated material is loaded directly onto ships and then the material is transported to an accredited waste disposal company for incineration or thermal desorption. In 2013, the transfer of the excavated HCH-material for shipping generated an odour cloud on the other side of the river Rhine in the city of Basel (CH) and emissions of HCH-dust (Forter 2015). Furthermore, HCH isomes have been detected in mothers' milk and milk from cows in the Region of Basel (Forter, 2015).

In November 2013, Novartis stopped the HCH-remediation work, which was then restarted in 2015. To prevent new emissions of HCH-dust from the remediation works, different precautionary measures were implemented (Steih 2016). For example, regular air and dust measurements are now carried out on the site and in the surrounding areas. Furthermore, the excavation of highly contaminated areas only takes place under large sealed tents that are equipped with a vacuum, and the extracted air is treated with activated carbon. In less contaminated areas, soil is excavated under large exhaust hoods with air filtration systems and in order to avoid dust formation, the surface is covered with a film of a degradable water-bonding polymer to bind the soil and dust. According to current estimates on the cost of the remediation project, the initial estimate of around 100 million euro will roughly double (Steih 2016).

Table 8. HCH waste production (tonnes) in France.

Location (company): period	HCH waste production	Actual situation
9 manufacturers with a total capacity of 1,800t/y	260,000 tonnes of HCH production residues have been located	No data for most of the sites
Huningue ,Haut-Rhin, Alsace (Ugine Kuhlmann): 1947 -1975	100,000 tonnes	HCH waste or concrete with HCH waste identified in 18 sites. Rehabilitation and investigation works carreid out in some sites. No work is being done in several sites.

#### 2.7. Germany

Ten companies manufactured lindane in Germany: four companies were located in the former German Democratic Republic (GDR) and six companies in the Federal German Republic (FGR). Altogether the amount of lindane produced is estimated to be about 20,000 t/y in the GDR and about 1500-1,700 t/y in the FGR. Estimated total HCH-isomers waste production is 236 000-246 000 tonnes for the GDR and 127,400 – 137,400 tonnes for the FGR (Vijn, 2006;

\_\_\_\_\_

Landesanstalt für Umweltschutz Baden-Württemberg, 1993; Heinisch et al., 2005). Unfortunately, it has not been possible to compile information on all production sites in the former FGR. Information on the actual whereabouts of the four production sites in former GDR is also not available. Several production sites have, however, been highlighed:

#### Magdeburg

Fahlberg List (FALIMA) was one of the most important chemical and pharmaceutical companies in the GDR. It produced lindane between 1946 and 1981. The company VEB Fahlberg produced 5,645 tonnes of lindane from 1967 to 1981. From 1960 to 1964 the production waste was deposited at a landfill in Cracauer Anger east of Magdeburg. Until August 1964, the disposal took place in two former quarries in Emden in Haldensleben. In total 76,000 tonnes were deposited in Emden (Heinisch et al., 2005;). Agricultural soils as well as plants surrounding the deposits have shown high levels of HCH isomers (Heinish et al., 1993).

#### Chemnitz (Karl-Marx-Stadt)

The enterprise Fettchemie in Chemnitz (known from 1953 to 1990 as Karl-Marx-Stadt), produced 30,985 tonnes of HCH from 1967 to 1977. The product was transported to Magdeburg where it was processed into lindane by FALIMA (Heinisch et al., 2005).

#### **Berlin-Adlershof**

The company VEB Berlin (Menarini Group since 1990) produced 4,617 tonnes of HCH and 1,245 tonnes of lindane between 1949-1961. During the period from 1951 to 1972 the company produced 28,452 tonnes of waste and 78,677 tonnes of HCH containing waste water. After being stored for a short while in the company's grounds, the solid waste products were deposited into the disused mine Regina in Freienwalde, Brandenburg, within a recreational area. The wastewater was deposited in so-called seepage ponds in the company's grounds (Heinischet al., 2005). Lindane has been found in well-water, surface water and sediments from the production site and in the vicinity. Between 1985 and 1989 water samples were found to contain alpha and gamma isomers up to 1,590 and 6,900  $\mu$ gr/l; delta 2,500  $\mu$ g/l and also beta (Börner, 2012). High levels of HCH isomers were also found in water and sediment (7820  $\mu$ gHCH/kg) samples from Teltowkanal in 2002.

#### Bitterfeld-Wolfen

The company Chemiekombinat Bitterfeld, located in the Bitterfeld-Wolfen region synthesized 93,000 tonnes of HCH between 1959 and 1982. Part of the HCH was supplied to other companies for lindane production, such as FALIMA. On-site lindane production amounted to 5,410 tonnes between 1967 and 1982. Part of the HCH production waste was deposited on site and then drifted off and was washed into Spittelwasser creek, which discharges into the Mulde river, a tributary of the river Elbe. Highly polluted untreated effluents were also discharged to the Spittelwasser creek resulting in the contamination of the Spittelwasser flat, the Mulde plain and the Elbe river, which do not comply with water chemical quality standards. Still today water discharged from the chemistry park emits HCH into the surface water system. It is estimated that 17,5 k/year of HCH isomers are emitted into the Mulde river. Contaminated sediments that are remobilised and dislocated during big floods, such as the 2002 flood event, are also important sources of HCH contamination to the water system (Jacobs, 2014).

With the aim of subsequent re-utilisation, 60,000 - 80,000 tonnes of HCH were deposited in the open brown coal mine "Antonie" near the factory site. Considerable amounts of waste were also buried in a site located 2 km from the mine. HCH and other organochlorine releases into the groundwater, surface water and atmosphere have been documented. High HCH concentration levels have been found in soils and groundwater close to the Antonie deposit, the former production locations and near Spittelwasser creek. In the vicinity of the southern production site, the upper aquifer (Quaternary) is highly affected by all four isomers which implies that large amounts of HCH were transferred into the soil/subsurface during production or from storage. In general, the HCH contamination covers an area of about 40 km2 and is therefore of regional scale (Wallbaum and Fuchs,1993; Wycisk et al., 2013).

#### Gernsheim, Darmstadt

The chemical company Merck produced lindane at its production site in Gernsheim, Darmstadt between 1954 and 1972. At the time, waste was deposited at the site as construction material for a parking lot. Between 2008 and 2014, the company renovated the site that covers an area of approximately 5,200  $\text{m}^2$  with 25,000 tonnes of HCH residues. Waste was sent to external incinerators to be disposed off (Merck,2009; Merck, 2016). Analytical data of water, sludge and suspended matter from areas around Darmstadt in 2004 showed the presence of high levels of HCH isomers, up to 4124  $\mu$ g/kg, in sludge from the waste treatment outlet at Merck Darmstadt (Heinisch et al., 2005).

#### Ludwigshafen

BASF manufactured lindane in its chemical complex located at Ludwigshafen. From 1955 to 1966, BASF deposited in a former sand and gravel pit located in the city's Maudacher Straße an estimated 780,000 m³ of waste, including HCH production waste. The polluted site has a surface of 4.5 hectares. In 1972, a shopping centre was built on the site by Metro AG and operated until 1999. In the 1990s, BASF installed 19 so-called safety fountains to prevent groundwater contamination. With this system about 300 cubic meters per hour of polluted water were pumped and flowed into the BASF sewage treatment plant. In the year 2000, the shopping centre was outsourced and the original buildings were dismantled. Originally it was planned to completely eliminate the waste stored underground, however, in 2009, the municipality decided that the best option was to seal the surface. Sanitation measures were carried out between 2013 and 2014, including the installation of a plastic sealant, a drainage layer and soil coverage and a groundwater monitoring system.

Evidence of groundwater pollution has led to a new de-contamination and rehabilitation programme that was approved in 2016. This includes the building of a 500 metre long sealing wall, excavation along the track of a 60 cm-10 m deep trench, where a special sealing compound will be used to act as a flow barrier in the subsoil. Also, refurbished wells, groundwater sampling stations and a water treatment plant will be installed jointly by BASF and the city of Ludwigshafen and will be ready to begin a groundwater remediation operation by 2018 (Ludwigshafen am Rhein Website, 2014 and 2016).

#### **Hamburg-Moorfleet**

The Cela-Merck subsidiary of Boehringer Ingelheim GmbH produced lindane between 1951 and 1984 in Hamburg. For three years it stored the waste at the site and in 1953 it began to recycle it to synthesize marketable pesticides (2,4,5-T and Bromophos). This activity resulted in the generation of dioxins and furans that contaminated the factory buildings, soils and waste. The soil and ground water under the factory was/is highly contaminated with HCH (260 tonnes), chlorobenzenes (550 tonnes), and PCDD/PCDF (6 kg toxic equivalents (TEQ) from spillages and leakages during the 30 years of the factory's production history.

The documented landfilled organochlorine waste from this factory (approximately 16,000 tonnes) are estimated to contain 52–171 tonnes of total PCDD/PCDF with 333–854 kg I-TEQ deposited along with 2,000 tonnes of HCH and other organochlorine wastes in at least seven landfills in Germany, including the mega landfill Georgsweder. The PCDD/PCDF content in the residue of the HCH decomposition finally resulted in the closure of the factory. Most of the PCDD/PCDF ended up in waste streams and were deposited on landfills. Waste was also destroyed on an incinerator ship in the open sea.

Exploration, remediation and containment activities at the production site started at the end of 1984 and were conducted until 1998. In order to secure the site, a cut-off wall (46 m in depth) was constructed and after the buildings had been removed the entire area was covered with an asphalt concrete covering. To assure that the 830 tonnes or so of organochlorine contaminants do not penetrate through the pores of the securing wall into the groundwater outside the contained area, a pump-and-treat system was installed to establish a pressure gradient for water flow towards the site. This is still ongoing. From the estimated 830 tonnes of chlorinated organics underground 10–30 tonnes have been pumped and incinerated over the past 15 or so years. Therefore, the largest share of the contamination load is still in the subsoil. (Götz et al., 2013; Weber and Varbelow, 2013). Similarly to Spolana, health problems appeared (chloracne) due to dioxin worker exposure during the production of Agent Orange (Weber and Varbelow, 2013).

#### Georgswerder landfill, Hamburg

Georgswerder landfill is one of the biggest waste disposal sites in Europe. It has a consolidated waste volume of about 7 million m³ deposited between 1948 and 1979. The landfill covers a ground surface of 45 ha and is about 40 m high. The waste mainly consists of 5 million tonnes of municipal waste and bulky waste and 1.77 million tonnes of excavated soil, as well as demolition waste. Moreover, in 10 basins, about 150,000 m³ of liquid hazardous waste was deposited between 1967 and 1974.

The total amount of chlorinated hydrocarbons in the oily phase of the landfill is estimated to be several thousands tonnes. 5,780 tonnes of HCH production waste from the former pesticide factory in Hamburg-Moorfleet was deposited in this landfill. 1,750 tonnes of this hazardous waste is HCH decomposition residues, containing 25–48 tonnes of dioxins and furans, which have been deposited in closed barrels.

Concerns about the dioxin content of the waste led to containment activities in 1984. Evidence of groundwater contamination in 1995 led to further remediation activities consisting of: the installation of a multilayered landfill cover; a peripheral leachate collecting system with a multistep purification plant; a landfill gas extraction system; and remediation of the contaminated groundwater with pump-and-treat systems. About 65,000 m³ of groundwater is pumped and treated annually. Computer modelling suggests that groundwater pumping at the southern landfill border will be necessary for a very long time. Also the landfill cover system and all other engineered structures will require intense aftercare measures. It is expected that the containment system will need to be renovated after about a hundred years (Götz et al, 2013).

Table 9. HCH waste production (tonnes) in Germany.

Location (company): period	HCH waste production	Actual situation
Magdeburg (Fahlberg List): 5,645 tonnes of lindane from 1967 to 1981	76,000 tonnes	n.d.
Karls-Marx Stadt (VEB Fettchemie): 30,985 tonnes of HCH from 1967 to 1977	n.d.	n.d.
Berlin-Adlershof (VEB Berlin Chemie): 14,617 tonnes of HCH and 1,245 tonnes of lindane between 1949- 1961.	During the period from 1951 to 1972 the company produced 28,452 tonnes of HCH solid waste and 78,677 tonnes of HCH containing waste water	n.d.

Location (company): period	HCH waste production	Actual situation
Bitterfeld-Wolfen (Bitterfeld CKB) 93,000 tonnes of HCH between 1959 and 1982. On site lindane production amounted 5,410 tonnes between 1967 and 1982.	60,000 tonnes of HCH waste was dumped into the mine "Antonie" and unkown amounts of waste were also buried in a site located 2 km from the mine.	HCH contamination covers an area of about 40 km <sup>2</sup> and is therefore of regional scale
Gernsheim and Darmstadt (Merck): 1954 – 1972	25,000 tonnes waste was sent to external incinerators to be disposed off (However, in Darmstadt encapsulated HCH seems to be stored. Therefore, quantities could be much more higher)	Site renovation finished in 2014. Analytical data of water, sludge and suspended matter from the vicinity of Darmstadt in 2004 showed the presence of high levels of HCH isomers, up to 4124 microgr/kg in sludge form waste treatment outlet at Merck Darmstadt
Hamburg –Moorfleet (Cela-Merck): 1951- 1984	16,000 tonnes	A graded demolition and renovation strategy was applied. The largest share of the contamination is still in the subsoil
Ludwigshafen(BASF)	n.d.	780,000 m <sup>3</sup> of industrial waste, including HCH production waste remain on site. Soil has been sealed. Ground water containment, monitoring and treatment facilities are under construction
Georgswerder landfill	5,780 tonnes of HCH production waste from Cela-Merck factory in Hamburg-Moorfleet 1,750 tonnes of HCH decomposition residues, containing 25–48 tonnes of dioxins and furans, have been deposited in closed barrels.	Containment, remediation and monitoring systems and activities in place.

n.d. – no data available

#### 2.8. Hungary

According to information provided by the National Food Safety Office (Pethö, personal communication. See references), three chemical plants produced lindane in Hungary:

- Nitrokémia Ipartelepek (Balatonfűzfő) is a state-owned company that produced lindane between 1962 and 1975. In 2006, the company profile changed from chemical industry to environmental protection. Experts consulted indicate that the site has not been cleaned up and may have significant lindane pollution.
- The company Budapest Vegyi Müvek produced lindane between 1966 and 1992 (Simon, personal com) in its factory located in Central Budapest. Waste was deposited at the site and also at other locations, such as Garé south of Budapest. Almost 2,500 tonnes of extremely hazardous materials were stored in appalling conditions (Greenpeace, 2016). Chemical barrels remaining in the factory were removed in 2015, although clean-up activities have not been undertaken. Random spot checks showed more then 500 times higher DDT concentrations than the Hungarian limits and about 300,000 times higher benzene and chloro-benzene levels in ground water than is allowed under EU limits.

Regarding the above chemical plants, the use of lindane was approximately 180 tonnes (not in active ingredients, but sold in formulated plant protection products (PPPs)), which is 7.5% of the total pesticide usage. Most pesticide waste was treated by incineration in hazardous waste incinerators, regardless of the content of POPs (Simon, personal com).

 A third company, the Petrochemical Company of Csepel and Komárom (Csepeli és Komáromi Kőolajipari Vállalat) may have formulated lindane containing pesticides (Pethö, personal comunication. See references).

There is no information on lindane concentration values, although all three sites may have significant lindane pollution (Simon, personal com).

Table 10. HCH waste production (tonnes) in Hungary.

Location (company): period	HCH waste production	Current situation
Balatonfűzfő, Veszprém county (Nitrokémia Ipartelepek):1962 -1975	n.d	No clean-up activities
Budapest (Budapesti Vegyi Művek): 1961 -1978.	n.d	No clean-up. The barrels with waste were removed from the area. There is still massive pollution in the soil in the production site and in other dumping sites located in Hidas and Garé
Csepeli és Komáromi Kőolajipari Vállalat (Petrochemical Company of Csepel and Komárom)	n.d	n.d

n.d. no data available

#### 2.9. Italy

#### Colleferro

The company Società di Navigazione Italo Americana Bombardi Pavodi Delfino (SNIA BPD) located in Colleferro, a town of the Metropolitan City of Rome in the Lazio region of central Italy was the only lindane manufacturer in Italy. HCH production wastes were buried at the site, contaminating superficial aquifers, while a canal serving the industrial plant spread the contamination into the Sacco river. Wastes were also deposited at several sites in the vicinity of the factory (Arpa1 and Arpa2), contaminating soils and groundwater. HCH concentrations of up to 51% in dry weight were found in soils where HCH wastes had been dumped.

Sediments and agricultural soil samples from near the banks of the Sacco river for an overall linear length of 72km downstream of the Fosso Cupo confluence are polluted with alpha, beta and gamma HCH above 0.01 mg/kg, which is the Italian limit set for public gardens. Samples from various wells and canals inside the industrial area, including Fosso Cupo have shown very high levels of HCH isomers (max 50087 mg/kg; mean value 2368 mg/kg, median 1,7 mg/kg) (Fuscoletti et al, 2015).

In 2005, an analysis of milk samples showed beta-HCH concentrations of about 20 times higher than the level allowed by law, highlighting the contamination of the food chain. A monitoring programme of the milk and meat produced in the area was established, as well as an epidemiological study of the population at risk in the three towns (Colleferro, Gavignano, Signs) closest to the offending industrial site (Ruzzenenti, 2013).

Remediation and reclamation activities have been carried out by the Ufficio Commissariale since 2005. These include: the restoration of the Fosso Cupo canal and the removal of 60 tonnes of contaminated sediments from it; the treatment of the rainwater it collects; the permanent storage in a safe site of 58,000 m³ of contaminated soil; the *in situ* sealing of about 3,500 m³ of heavily HCH contaminated soil; the construction of a hydraulic barrier to collect the contaminated water downstream of the sites Arpa1 and Arpa 2; a deeper drainage system to collect the contaminated water of the medium depth aquifers; and the building of a treatment plant for the water collected by this net. Before being introduced into the distribution net, drinking water from wells located in the industrial area is treated with activated charcoal. Monitoring and remediation activities in the area are ongoing (Fuscoletti et al, 2015).

Table 11. HCH waste production (tonnes) in Italy.

Location (company): period	HCH waste production	Current situation
Colleferro, Lazio, Rome (Società di Navigazione Italo Americana Bombardi Pavodi Delfino SNIA BPD):	58,000m³ of contaminanted soil have been displaced in a safe site. 3,500m³ of heavily contaminated soil reamain in situ	On-going monitoring and remediation activities.  Drinking water treated with activated charcoal before being introduced in the distribution net.  Epidemiological study of the population at risk in the three towns closest to the offending industrial centre (Colleferro, Gavignano, Signs).

#### 2.10. Latvia

According to the information provided by the Ministry of the Environment none of the current POPs, including lindane, has ever been produced in Latvia (Ozola, personal communication. See references).

Since 1999, the use of lindane has been prohibited. However, information given in the National Action Programme on Persistent Organic Pollutants 2005–2020 shows that 49 tonnes of lindane were imported in period 1995–1999. Lindane was used as insecticide of complex exposure to combat insects in, for example, coppices, non-producing orchards and cereals.

There is no awareness about any disposal or polluted site. Most of the POPs stocks and stores have been eliminated with national and EU supported programmes (Vijgen, personal communication).

# 2.11. Poland

Several production sites have been noted:

# Jaworzno, Silesia

The company Organika–Azot Chemical Plant located in Jaworzno, Silesia, has been the only manufacturer of lindane in Poland. Between 1956 and 1982 it produced about 3,900 – 4,450 t/year of lindane and 35,000 tonnes of HCH (Vijgen, 2006; Stobiecki, 2013).

Until 1967 waste was probably placed in the plant and its surroundings. In 1967, it began to deposit its waste, including 10,000 tonnes of HCH isomers, in the Rudna Góra landfill located also at Jaworzno in the basin of the Vistula river. The landfill occupies an area of 20 hectares and stores over 160,000 tonnes of waste, out of which 88,000 tonnes are hazardous waste. This landfill has been placed on the list of hot spots drafted under the Helsinki Convention on the protection of the Baltic Sea (Stobiecki, 2011).

Monitoring of the landfill's groundwaters have detected up to 300  $\mu$ g/l of pesticides and up to 100  $\mu$ g/l of pesticides have been detected in the Wawolnica Stream and in trenches surrounding the landfill (Stobiecki, 2013).

Waste storage at the site ceased in 2001. The company and the municipality have carried out some practical measures to cap the spread of contaminants from the landfill, including: building a network of drainage trenches around the site; building a leachate pumping station; and providing a temporary cover over the major part of the landfill using inert material. In 2003-2004, the plant modernized its production sewage treatment technology at its treatment station to remove pesticide contaminants via an activated carbon bed. In 2009, the existing pumping station was modernized and all leachates intercepted from the landfill were treated and now comply with applicable standards. The Central Institute of Mining in Katowice, the town of Jaworzno and the Organika Azot Chemical Plant developed in 2011 an international research project named FOKS (IETU News, 2012) to identify and select the best technology to stop emissions of contaminants from the landfill.

Table 12. HCH waste production (tonnes) in Poland.

Location (company): period	HCH waste production	Current situation
Jaworzno, Silesia (Organika-Azot Chemical Plant): 1956- 1982	35,000 tonnes  Considering the mix of soil and waste this quantity increases to 140,000 tonnes	n.d.
Jaworzno (Rudna Góra landfill)	More than 160,000 tonnes of waste of which 88,000 are hazardous (all mixed)  Over 17,000 tonnes of lindane production waste	Network of drainage trenches around the site and leachate pumping station  There are monitoring and rehabilitation proposals

n.d. no data available

#### 2.12. Romania

According to the information provided by the Ministry of the Environment, two companies produced lindane in Romania: (Paun, personal communication. See references).

- SC Oltchim SA produced Lindane between 1969 to 2006; the history of the company can be found at the following link: http://www.oltchim.ro/en/index.php?name=about-us/history and,
- Turda Chemical Plants (U.C.T.) produced Lindane during the period 1954 -1983; the plants activity was ceased in 1998.

However, a country report from 2005 indicates that Romania produced 6,431 t/year of HCH in 1989. In 2001 it decreased to 555 tonnes. In total it is estimated that Romania produced 250,000 tonnes of HCH waste (Vijgen, 2006). Additionally, a report by the Ministry of Environment and Sustainable Development of Romania (2008) also indicates that Romania produced 90,000 kg of lindane in 2005 and 12,000 kg in 2006. 7,800 kg and 12,000 kg of lindane were exported to Spain in 2005 and 2006 respectively.

According to the inventory, there are no stockpiles of lindane at the national level. 2010 was the last date when a stockpile of lindane was identified, namely 563 kg of Lindatox (containing 20% lindane), kept by an economic operator in a storehouse of plant protection products. Following an inspection by the National Environmental Guard and the local authorities, the holder of the stockpile eliminated it with a specialized company in May 2010 (Ministry of Environment and Forests of Romania, 2010). Another source claimed the illegal trade of obsolete HCH as a pesticide was taking place (Mogos, 2016).

A preliminary inventory identified seven sites potentially contaminated with HCH. Three of these sites are localized at SC Oltchim SA, and the other four are localized on the site of the company known as Turda Chemical Plants (Paun, personal communication. See references).

HCH production waste from the former UCT Turda Chemical Plants was stored, from 1954 to 1983, in four uncontrolled settlements in the Turda area, including Posta Rât. (Violeta, 2010).

Posta Rât is located on the left side of the river Arieş in the unincorporated territory of the Municipality of Turda, occupying an area of approximately 10 ha. Studies conducted on the Poşta Rât site have shown that the estimated total quantity of waste deposited here over time adds up to 10.000 m³, the equivalent of 18,500 tonnes of toxic substances. A project for the rehabilitation of this site, financed through the Environmental Sectorial Operational Programme, is being conducted⁴.

Table 13. HCH waste production (tonnes) in Romania.

Location (company): period	HCH waste production	Current situation
Ramnicu Valcea, Oltenia(SC Oltchim SA): 1969 -2006	Romania produced 250,000 tonnes of HCH waste.	The plant is still operating.  3 uncontrolled disposal sites in SC Oltchim SA area.
Turda, Cluj (Turda Chemical Plants (U.C.T.): 1954 -1983	Romania produced 250,000 tonnes of HCH waste.	4 uncontrolled settlements in Turda area  Posta Rât, occupying an area of approximately 10 ha, the equivalent of 18,500 tonnes of toxic substances. A rehabilitation project is being conducted.

# 2.13. Slovakia

Juraj Dimitrov Chemical Enterprises (CHZJD) in Bratislava was the single lindane producer in Slovakia. Between 1956–1966 this factory produced more than 13,000 tonnes of Lindane. Several authors report large stockpiles of HCH-waste (around 90,000 m³) and significant amounts of polluted groundwater (millions of m³) (Vijgen, 2016).

Chemical waste from the company was deposited at the Vrakuna landfill in the city of Bratislava in part of the riverbed of the Malý Dunaj river. The landfill has a crescent shape and its surface is about 46,500 m². It is estimated that the volume of waste is about 90,000 m³. In 1989 it was covered with an inert material. After a hydropower station in Gabcíkovo on the Danube river began to operate in 1989, the level of the underground water increased, reaching the chemical waste and polluting the local ground water. As a consequence, local wells have not been in use since then. In February 2016 the Environment Ministry announced the approval of a budget to carry out the encapsulation of the landfill (Machlica, 2015; Slovak Spectator, 2016).

Table 14. HCH waste production (tonnes) in Slovakia.

Location (company): period	HCH waste Production	Current situation
-------------------------------	----------------------	-------------------

<sup>&</sup>lt;sup>4</sup> Details about the project can be found at the following link: <a href="http://postaratturda.ro/?lang=en">http://postaratturda.ro/?lang=en</a>

Bratislava (Juraj Dimitrov Company)(CHZJD): 1956-1966	90,000 m³	n.d.
Vrakuna landfill (Bratislava district)	n.d.	Waste remains on site. Engineering, hydrogeological and geological surveys have been carried out. Environmental ministry has approved a budget for encapsulation.

n.d. no data available

# 2.14. Spain

According to the information provided by the Spanish Environmental Authority (García, personal communication. See references), lindane has been produced at the following locations:

# Basque -Country (Barakaldo, Bizkaia)

According to the information provided by the Basque Environmental Authority (Betanzos, personal communication. See references), two companies produced lindane in the Basque Country between 1947 and 1987:

- Nexana Celamerck, located in Asua-Erandio that produced lindane from 1952 to 1982. It is estimated that around 7,000 tonnes of HCH waste residues were generated by
- Bilbao Chemicals located in Ansio-Barakaldo, which produced lindane from 1947 to 1987. This plant generated around 75,000 tonnes of HCH waste residues.

Both companies belonged to Merk and Boehringer (del Moral, 2012). It is estimated that together these companies generated a total of 82,000 tonnes of waste. This includes 5,000 tonnes of pure waste isomers and 77,000 tonnes of mixed waste that were dumped in at least 36 different sites, resulting in the contamination of at least 410 ha of land and 450,000 m<sup>3</sup> of soil. The authorities estimate that between 500,000 and 1,000,000 tonnes of HCH-contaminated residues have been disseminated in this region. Many of the former dumping sites belong today to the urban area of Barakaldo and its surroundings.

As a consequence of the production of the lindane pesticide in the Basque Autonomous Community and the inadequate management of the residues produced by this activity, during the last decades of the 20th century a number of highly contaminated sites were generated in the Basque Country which represented a clear threat to public health as well as for the environment, supposing also a brake that prevented the development of the areas in which they were located. In the 1990s, the identification of potential sites contaminated by HCH waste were carried out in the area of the Autonomous Community of the Basque Country. This taks was focued on a) the plots where the two producer companies operated and b) those sites where uncontrolled disposal of HCH residues were suspected to be dumped. In this way 40 sites were identified.

Due to the characteristics of soils contaminated with HCH residues, and after an analysis of alternatives, the best solution identified for its management was soil excavation and its deposit in a security infrastructure constructed for that purpose. Thus contaminated soils from the 40 sites that had been previously identified were confined in two security deposits:

the Loiu security cell built in that municipality, and the Argalario security cell built in the municipality of Barakaldo. In 1993 the Government of the Basque Country built a storage site for pure lindane-waste and several temporary deposits for the HCH-polluted soils. The Government also built two landfills, Argalario (security deposit) and Loiu, between 1996 and 2002, for the storage of waste and contaminated soils extracted from 27 polluted sites. A process of soil cleaning up was active during those years. Argalario deposit stores 340,000 m³ and Loiu landfill stores 113,718 m³ of waste and contaminated soil. These storages are still monitored and their leachates treated. (Escolar, 2015; Vijgen, 2006).

This last infrastructure was submitted during its construction and after the constructive period to intense environmental and safety controls. This approach and, especially information to the citizens, is referred to in section 4.1 as an example of best practice.

The pure HCH residues left in the facilities of the producing plants were treated through the BCD (Based Catalyzed Decomposition) process, a chemical technology that was being developed by the US EPA (see section 3.3.1 for additional information). Its treatment was carried out in a plant built for that purpose in the land in which it developed the business Bilbao-Chemicals, one of the activities producing this waste. This treatment plant for pure waste, which operated from 1999 until 2001, treated 3,211 tonnes of waste and generated 500 tonnes of refuse.

In relation to water pollution, in recent years the following conditions have been identified for water bodies in the Basque Country:

• Oiola Dam Reservoir (Bizkaia). In July 2008, anomalous levels of HCH were detected in the Loiola reservoir (Bizkaia), ranging from 13 to 154 ng/L (Ekologistan Martxan, 2016), that supplies drinking water to 100,000 inhabitants. It was then closed immediately until the quality of the water could be guaranteed with maximum sanitary security for the population. Through an interinstitutional commission, different studies were carried out to determine the origin of the contamination and to eliminate the corresponding foci.

At present the reservoir is subject to periodic water and sediment quality controls.

- Transitional water mass Nerbioi (Bizkaia). The Hydrological Plan of the Eastern Bay of Biscay determines the existence of bad chemical status in two transitional water masses (Nerbioi interior and Nerbioi exterior) and in different sections of its tributaries, with local overruns of the new quality standards established for HCH (20 ng/L). This poor condition was not evaluated in the same way in the past since previous quality standards were less demanding (100 ng/L). In these bodies of water, the Hydrological Plan proposes the development of an action plan for the achievement of good chemical status, as well as an extension of objective compliance until 2027.
- Río Zadorra (Alava). During water controls in 2013 and 2014 HCH levels were detected in the checkpoint Vitoria-Trespuentes. Seven of the 23 samples exceeded the maximum permissible concentration in water; showing levels between 0.049 and 0.139 µg/L. In February 2015, the Hydrographic Confederation of the Ebro informs the Basque Water Agency about the existence of HCH concentrations above the Environmental Quality Standard at station 0179-FQ (Zadorra / Vitoria-Trespuentes). During 2015, when the maximum allowable concentration of HCH was exceeded four times, the Basque Water Agency concluded that the HCH isomers came from the landfill Gardelegi, whose leachate is connected to the Crispijana station. Additionally, it was discovered that these contaminants were not detected in river samples when

the river flow was over a thousand litres per second, which indicated that the leaching of lindane is a continuous process, but that during high river flows lindane is not detected.

As a result of this situation the URA executed a control to determine the origin of municipal solid waste in the municipal landfill. In this context, the owner of the infrastructure has been urged to present an action plan to correct this situation, which is being developed at the moment. This issue is of special concern since the presence of lindane in the river is associated to the leacheates from a municipal landfill, instead of the usual illegal dumping.

In the Basque country 50 million euro has been spent on sites where 82,000 tonnes were dumped. Of this amount, 8.4 million euro was spent to treat 3,500 tonnes using the BCD process. The remaining was used for two safe hazardous waste landfills. This points at costs between (at least) 0.53 euro (landfilling: 41.6 million euro for 78,500 tonnes) and 2.40 euro (BCD) per kg HCH (Osterhuis and Browver, 2015).

# Galicia (O Porriño, Pontevedra)

From 1947 to 1964 the pharmaceutical company Zeltia produced lindane together with other pesticides, including DDT, in its factory located in O Porriño in the region of Galicia. The company continued formulating lindane-based products for some years. 1,000 tonnes of lindane production waste was dumped mainly in the industrial area of Torneiros in the municipality of Porriño, (Pontevedra) until 1964. Afterwards, the municipality used the area as a landfill site for construction waste. In 1975, social houses were built on this site and in 1990 a bicycle lane was built. The waste was dispersed during the years due to levelling works of the area associated with road construction and urban development (El Atlántico, 2012).

The waste generated at the production plant was also dumped at other spots in the region, was reused as construction, road repair and building material as well as an insecticide. These activities led to several secondary HCH polluted areas. A study of the area in 1999 revealed several areas with high concentrations of HCH isomers, in soils, groundwater and wells used for drinking water. Levels up to 1,000 mg/kg were detected in soils. Neighbours living in some of the social buildings constructed over the dumpsite were relocated in 2010 (Faro de Vigo, 2010), however, still in 2012, neighbours from other buildings were demanding to be relocated outside the polluted area (El Atlántico, 2012).

The soils in O Porriño (Torneiros area) where there were industries dedicated to lindane production, were included in the Plan for Contaminated Soils and the Operation Programme of the Xunta de Galicia. The first analyses (1998) showed contaminant values above the quality objectives, leading to these soils being declared as contaminated according to different regulations of the Xunta de Galicia. In this area there are now various installations that are subject to environmental authorisations. These include Syngenta Agro and Astra Zéneca Farmacéutica, which have piezometric networks showing high levels of lindane in the waters.

Among the most urgent actions that were taken by the regional authorities of Galicia in Torneiros was: a) the fencing of 3.2 ha of soils with a minimum concentration of 2 ppm of HCH; b) the closure of the wells in the area; c) the restriction on agricultural use of the soil; d) encapsulation of the main pollution source with vertical bentonite-cement panels, 30 m maximum depth (to embed them in the granite bedrock); and e) excavation and disposal of soils with HCH concentrations higher than 5 ppm in hazardous waste landfills.

Areas with concentrations of HCH isomers between 2-5 ppm were covered with sealants.

Regarding the management of the polluted public land outside the encapsulated volume, insitu biodegradation has been considered the best technique. The Galician Autonomous Government is backing an investigation of these techniques in cooperation with different research groups. The total contaminated area covers 1 km², and 150,000 m³ of polluted soil have been encapsulated (Crespo, 2001; Varela-Castejón and Lozano, 2008; Rodríguez, 2009). Piezometric networks of companies installed in the site nowadays show high levels of lindane in groundwater (García, personal communication. See references).

# Aragón (Sabiñánigo, Huesca)

From 1975 to 1988 the company INQUINOSA produced lindane at its factory located in the city of Sabiñánigo in the region of Aragón on the bank of the river Gállego (tributary to the river Ebro). The company continued formulating lindane until 1992. It is estimated that the company produced 6,800 t/year of solid waste and 300 to 1,500 t/year of liquid waste, this is between 115,000 and 160,000 tonnes of HCH-waste.

HCH-waste was mainly dumped in two unlined landfills located in Sardas and Bailín, in the surroundings of Sabiñánigo:

- From 1975 to 1983, HCH-waste residues were carried to the landfill of Sardas. The Spanish Environmental Authorities (Gracía, peorsonal communication) estimated that it currently contains 60,000 m³ of HCH solid waste, about 30 m³ of dense non-aquous phase liquid (DNAPL) and another 350,000 m³ of hazardous municipal and industrial waste. In 1992, a superficial waterproofing was carried out.
- From 1984 to 1989, the HCH-waste residues were transported to the landfill of Bailín. In 1994, a superficial waterproofing was also carried out in this landfill, which was ineffective. In 2014, to avoid the leaching of contaminants and the pollution of the Gállego River, the regional Authorities of Aragon transported the wastes from the Bailin landfill to a new safety cell in the same ravine, which contained a lower and upper coating and leachate treatment. In this new safety cell there are 65,000 tonnes of HCH solid waste and 342,000 tonnes of contaminated land (García, personal communication). In the former old landfill, it is estimated that there are 25 m³ of liquid waste in the subsoil (Férnandez et al., 2013; Calleja, personnal comunication).

These two landfills, as well as the production site, are important potential sources of pollution from HCH isomers and other toxic substances (other POPs, heavy metals, etc.). High levels of dioxins (2,633 ng/k) have been detected in the HCH-waste deposited in Bailín (Ecologistas en Acción, personal communication). Other chemicals and 90,000 m³ of polluted soil still remain in the production site, which still has not been dismantled. About  $1.2 \, \text{m}^3$  /y and  $0.8 \, \text{m}^3$ /y of DNAPL are pumped from Sardas and the former Bailín landfills respectively. These residues are transported to France to be incinerated.

The dam in the Gállego river is totally clogged up apart from 1 m at the top of it. The Sabiñánigo reservoir dam received direct emissions from the factory during its period of activity. River sediments have high concentrations of HCH isomers, other organochlorinated chemicals, heavy metals, PAH and other toxic substances (CHE, 2010). Before the three carbon active STPs were installed, it is estimated that the Gállego river received 140 kg/year of HCH from both landfills through surface water inputs (Fernández et al, 2013). There is a monitoring procedure for the Gállego River carried out by the local authorities (Protection

Civil) to coordinate the administrations involved in purifying and making drinkable water from the Gállego river, downstream of the sites. Containing this pollution is the work of 20 people.

From 1992 to 2015, 54 million euro was invested in containing pollution, with 9% of the funds coming from the EU, 21% from the Spanish Ministry of Agriculture, Food and Environment, and 70% from the Government of Aragón.

The transfer of waste from the old Bailin landfill to the new safety cell produced soil contamination and generated a peak of HCH in the water of the Gállego River, which led to a cut in the supply of drinking water to 6,000 inhabitants of the area for some 30 days.

All this means that 50 ha of land and three aquifers are contaminated and probably in a similar state to the river bed of the Gállego river and its reservoirs. It is estimated that the complete clean-up and rehabilitation will last 25 years and cost 550 million euro (Ortega, 2016; Martínez, 2016). Regarding the ruin of the Inquinosa plant, as a preliminary step towards its demolition, it is planned to map out the structure of the plant and the soils in the surrounding area. This is a total of 31,000 m². The overall volume of waste exceeds 130,000 tonnes of HCH solid, 6,000 tonnes of liquid waste (DNAPL) and about 1 million tonnes of contaminated land.

Regarding the restoration of the polluted site, the Aragón Government's Department of the Environment is currently testing the decontamination of the groundwater through chemical oxidation within the framework of an EU Life Plus demonstration project named Life-DISCOVERED 2012 (GA, 2016a). See section 3.3.12 for further information on the method and the project.

#### Castilla y León (Borobia, Soria)

In 1988, 70 tonnes of HCH waste from the lindane factory in Barakaldo were dumped in an abandoned mine in the municipality of Borobia in the province of Soria. Complains from neighbours obliged the company to collect the waste. In 2013, an analysis of the water in the entrance to the mine performed by the water authorities showed beta-HCH concentrations of 0.025  $\mu$ g/l in 2013 and 0.017  $\mu$ g/L in 2015 (ASDEN, 2015). Additional water samples collected and analysed by the CHE showed values below the detection limit (DL) (<0.015  $\mu$ g/L) (ASDEN, personal communication). This DL is slightly above the screening value stablished for lindane in groundwater samples (0.01 $\mu$ /L) under Spanish legislation, which is used to justify the need for further studies to confirm whether a soil can be considered as polluted (Royal Decree 2005).

This situation is confirmed by the environmental authorities:

- A report from the Ebro Basin Organization dated 16 November 2015 indicates that traces of beta-HCH have been detected although in much lower concentrations than set out in the Directive 2006/118/CE.
- A report by Service for Environmental Prevention and Climate Change dated 16 May 2016 indicates beta-HCH y alfa-HCH has been detected in concentrations above the generic reference levels set out in the Royal Decree 9/2005.

#### Castilla y León (Cabria, Palencia)

There is another case of illegal dumping of 360 tonnes of lindane in the town of Cabria (Aguilar de Campo -Palencia-) at the same time as the discharges were taking place at the Borobia mine. In May 1988, the authorities (including the autonomous government) acted diligently and properly decontaminated the site affected by the spill and opened the corresponding disciplinary proceedings that ended with a criminal sentence, which was

upheld by the Spanish Supreme Court (SSC, 1993).

#### **Navarra**

The companies INQUINOSA and Bilbao Chemicals also dumped HCH waste in Navarra, a region between the Basque Country and Aragón. There is evidence of dumping in the municipalities of Viana and Iguzquiza (AV, 1990; AIguzquiza, 2016).

In 2016, an investigation began to assess the current status. This review is not motivated by any health or environmental problems requiring urgent action. The objective is to assess the current state of the affected areas. No results are available yet.

Table 15. HCH waste production (tonnes) in Spain

Location (company): period	HCH waste production	Current situation
Porriño, Galicia (ZELTIA): 1947- 1964		1 factory (INQUINOSA) pending dismantling and clean-up.
Sabiñánigo, Aragón (INQUINOSA):1975-1988		4 security landfills containing HCH-waste.
Barakaldo, Basque Country (BILBAO CHEMICALS):1947-1987		1 uncontrolled landfill.
Erandio, Basque Country (Nexana Celamerck):1947-1987	200,000 tonnes	HCH polluted sites pending decontamination in Aragón, Basque Country and Galicia.  Polluted sites pending identification in several regions including Aragón, Castilla y León, Galicia, Navarra and Basque Country.  High levels of HCH isomers in surface and groundwater from

# 2.15. The Netherlands

Technical HCH was produced in the Netherlands, primarily between 1947 and 1952 at five sites. Very little information is available on the amounts of technical HCH produced. In the early 1950s the production shifted to lindane, resulting in the production of huge amounts of HCH isomer waste that was stored at production sites and also mixed with construction materials and deposited in hundreds of sites, including agricultural areas around the country. Over 400,000 tonnes of contaminated soils were generated by just one of the manufactures located in Hengelo. Remediation activities have been carried out at production and dumping sites (Langenhoff, 2001; Vijgen,2006; Bouwknegt,2016). Several sites have been geohydrologically isolated to reduce groundwater contamination. Groundwater is being monitored, pumped and treated at different sites. Also soil bioremediation activities are ongoing.

Osterhuis and Browver (2015) indicated the costs of about 40 locations in the Netherlands where soil and groundwater pollution by HCH/lindane has been remediated.

# Twente (Overijssel)

The company Stork & Co. produced HCH in the city of Twente between 1948 and 1952, disposing of the waste in an open storage. The company was sold to Akzo in 1954. At that time, at least 5,500 tonnes of HCH were being stored on the company's premises. In the 1950s and 1960s a portion of the remaining waste isomers in the storage were illegally collected and mixed with soil for construction purposes and hence dumped at numerous locations in the surroundings, such as Borne and Oldenzaal, some 10-20 km away from the source. In 1975, due to a public outcry following a massive amount of fish deaths in a canal next to a waste storage site, the authorities asked Akzo to pay for the removal of 4,000 tonnes of waste isomers. 500 tonnes were sold to another Dutch factory for reprocessing. 22,500 drums were packed and transported to a salt mine in Eastern Germany. In 1983, after the entry into force of the Interim Act on Soil Clean-up, an inventory of polluted sites was performed. From a total of 132 suspected polluted sites, 42 were finally selected for clean-up and further investigation. At the end of the 1980s, a temporary storage site was established at the site where over a number of years around 200,000 tonnes of excavated polluted soil from contaminated areas was stored. As at that time no proper technology was able to treat HCH, the government invited companies to try their technology in order to prove its feasibility. The 200,000 tonnes of contaminated soil was finally treated at the beginning of 2002. In 2006, another 200,000 tonnes of soil in less contaminated areas remained untreated (Grinwis, 1992; ICIS News, 2004; Vijgen, 2006).

The total costs for the actions executed are around 27 million euro. Due to the fact that it is not clear if and when the remaining contaminations will be treated it cannot be concluded what the final costs will be.

Estimating that from the original amount of 5,500 tonnes of HCH residuals, 4,000 tonnes were transported to Eastern Germany which means that an amount of around 1,500 tonnes that were spread in the region has created a damage of around 27 million euro. It may be obvious that a direct elimination and destruction or even encapsulation of these 1,500 tonnes would have been a fraction of the money spent till present in the region clean-up.

#### **Deveneter (Overijssel)**

Unknown quantities of HCH were produced in a pesticide factory located in Deventer between 1946 and 1962. The production waste was temporary stored in factory buildings and on the site, and possibly part of it was also buried on site. The soil was first analyzed in 1985 revealing that the site's soil and groundwater was contaminated with high levels of HCH and its decomposition products (mainly chlorobenzenes). It is assumed that waste water was discharged through the municipal sewer system.

In 1990, the authorities decided that the geohydrological isolation of the site was the best option with supplementary remediation measures in order to allow building development. Demolition works were carried out, a top layer of 20,000 tonnes of soil was excavated and removed. Subsequently, a one-metre insulation layer of clean soil and an asphalt sealant was applied in order to prevent further spread of the pollution through groundwater. A groundwater extraction system has been in operation since 1994. Contaminated groundwater was treated by a combination of biological and granular activated carbon (GAC) treatment. This was the first site in the Netherlands where based on the assessment of human toxicological hazards with the CSOIL-model, with approval of the Ministry of the Environment,

redevelopment of the site was allowed after a partial clean-up. Remediation of the subsoil by soil vapour extraction is still in progress (Cobouw, 1994; Grinwis, 1992; Bouwknegt, 2016).

In 2006, a list of around 290 suspected HCH contaminated sites in the Overijssel region was compiled (VROM Press Release, 20.02.04, cited in Vijgn (2006)). The Province of Overijssel expects to achieve the goal of cleaning up the soil by 2030 (IHPA, 2016).

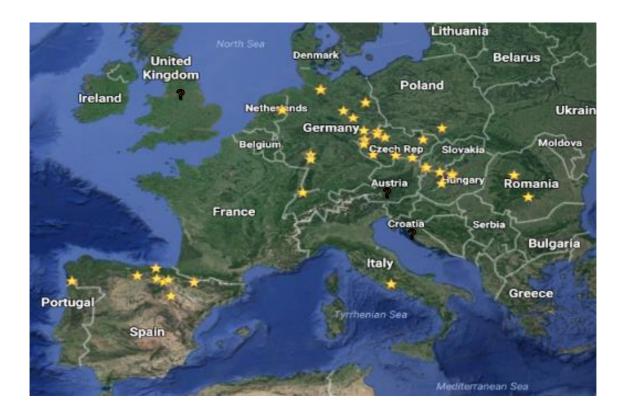
Table 16. HCH waste production (tonnes) in The Netherlands.

Location (company): period	HCH waste production	Current situation
Lindane produced at 5 sites between 1947 and 1952	Over 400,000 tonnes of contaminated soil.	Groundwater is being monitored, pumped and treated at different sites. Also soil bioremediation activities are ongoing.
Twente, Overijssel (Stork & Co): 1948-1952	5,500 tonnes of HXH isomer waste stores on site in the 1970s 400,000 tonnes of polluted soils excavated.	Remediation activities have been carried out since 2002.
Deveneter, Overijssel: 1946-1962	20,000 tonnes of contaminated soil excavated.	Geohydrological isolation and remediation of the site. Ongoing underground water monitoring and treatment.
Dagra, Bunschoten, Province of Utrecht 1984-1987?	Volume excavated around 11,000 m³. Many years of groundwater plume. Remediation and later hydraulic containment.	

# 2.16. United Kingdom

The UK, like France was one of the "parent countries" of HCH. It is estimated that it produced 1,200 tonnes of lindane (Vijgen, 2006). No information is available on the manufacturing sites, production or treatment of waste. In the most recent NIP for the Stockholm Convention the UK has declared to start up historical investigations on the lindane production and HCH-waste (see overview at website of Stockholm Convention).

Figure 2. Identified production and contaminated sites ( $\stackrel{*}{}$ ) + countries production but not information on the sitees (?)



# 3. CONFINEMENT, TREATMENT AND DE-CONTAMINATION OPTIONS

#### **KEY FINDINGS**

- Several methods for the remediation of lindane, HCH-waste and HCH contaminated soil and groundwater have been developed. Especially the management and treatment of HCH-waste is complex, as HCH-waste contains about 70% chlorine.
- The conventional and most widely used methods include: the excavation of contaminated soil and its containment in dedicated landfills; the confinement of contaminated groundwater or soil in order to contain it within a site; pump-and-treat methods for groundwater and incineration.
- Physical treatment methods separate the contaminants from the soil/water matrix by using physical differences between the matrix and contaminant. The chemical treatment methods destroy, fix or concentrate the contaminants by using chemical reactions.
- Biological treatment methods involve the use of microorganisms or vegetation that can destroy or transform contaminants to less hazardous chemicals, as well as extract and accumulate them.
- Many of the physico-chemical and biological treatment methods have been tested only
  in laboratory or batch-scale experiments, and, thus, further field scale experience is
  needed.
- The recycling of HCH (70% chlorine content) to HCl should be considered and further investigated as it could be a profitable business for industry, especially since there are considerable quantities of HCH waste on a global scale. However, special care should be paid on preventing potential emissions of more hazardous substances, e.g. dioxins.

Due to the widely intensive use of lindane in the past and the uncontrolled disposal of its production waste, lindane and other HCH isomers can be found in air, water and soil samples all over the world. Since the nineties, extensive attention has been paid to the clean-up of environmental sites polluted with this hazardous chemical.

A number of methods have been developed to treat and manage waste and to remove lindane from soil and water. Conventional methods include: excavating contaminated soil and its containment in dedicated landfills; confining contaminated groundwater or soil in order to contain it within a site; or pump-and-treat methods for groundwater. These methods have been used in the remediation of many sites contaminated with lindane and HCH in the Europe (see chapter 2). However, these methods are very expensive and disposing HCH in a landfill or confining it does not destroy or remove the contaminants from the soil matrix. They are therefore not considered as sustainable definitive remediation methods. Another traditional method is the combustion of the contaminated waste. However, this is often expensive and has the potential to create even more toxic compounds such as dioxins and furans.

Treatment-based approaches, which include different physico-chemical and biological methods, destroy, remove or transform contaminants from the contaminated material (e.g. waste, soil or groundwater). Therefore, these methods are considered to have more added environmental value than the more conventional methods mentioned above.

Treatments may be classified as *ex situ* and *in situ* approaches. *Ex situ* approaches are applied to excavated soil or extracted groundwater, whereas *in situ* approaches use processes occurring in unexcavated soil/unextracted groundwater, which remain relatively undisturbed. In *ex situ* remediation the conditions can be controlled to make the process more efficient, but the whole process is often very costly. *In situ* remediation costs less but the delivery of the treatment to the contaminated site is challenging and the control of favourable conditions and possible harmful side effects (e.g. formation and release to the environment of other harmful chemicals) may be more difficult.

This chapter provides a selective overview of the achievements and currently available confinement, treatment and de-contamination techniques, as well as examples of field remediation cases. In these cases, physico-chemical and biological approaches have been carried out to remove lindane and its isomers from contaminated soil and aquatic compartments under different environmental conditions.

#### 3.1. Containement

Containment is a common technique adapted to contain contaminated ground waters or soil within a site, or to divert ground or surface waters away from a contaminated site to limit their contact with people, the ecosystem on the sites, and to minimize the potential for further contamination.

The objective of containment is achieved by the construction of a low-permeability or impermeable cut-off walls. Most of the walls are built with soil, bentonite, and water mixture. Walls of such composition provide a barrier with low permeability and chemical resistance at low cost. The desired permeability of the completed wall is typically  $1 \cdot 10^{-3}$  to  $1 \cdot 10^{-6}$  cm/sec.

Wall construction is often performed in a continuous manner with the simultaneous processes of trench excavation. There is a substantial cost increase for walls deeper that 30 m.

Containement and sealing have been used in the remediation works of many lindane and HCH contaminated sites in the EU, e.g. in Germany, the Netherlands, Spain (see section 2 for further information).

# 3.2. Combustion

# 3.2.1. Dedicated incinerators

The incineration of chlorine compounds is an expensive option since high energy and sophisticated equipment are needed:

- a) the waste is incinerated with the help of oil or another fuel at high temperatures, commonly in the range of 1200-1400°C, to convert the chemicals into gases which then ensure their complete decomposition; and
- b) high technology emission control equipment should be incorporated to limit the generation and emissions of more hazardous contaminants to levels below the limits of detection, such in the case of dioxins.

It should be taken into account that when considering incineration as a remediation method for contaminated matrices, e.g. soil or sediment, not only the contaminants, but also the matrices incinerated, which is an additional setback due to higher complexity. The volumes

of material are much greater, and soil particles, steel drums and many other materials do not burn. Therefore, it does not seem to be the most cost-effective technology when large amounts (hundreds or thousands of tonnes of chemicals bound to matrices) need to be treated. This should also be taken into account when dealing with complex mixtures of wastes. This makes this option expensive and not very efficient.

Incineration has been widely used in the disposal of HCH-waste and soil and other material contaminated with lindane and HCH in the EU.

#### 3.2.2. Cement kilns

Cement kilns are primarily designed to burn limestone at temperatures between 1400-2000°C and are generally fuelled by fossil fuel. Their use to destroy toxic chemicals entails co-fuelling the kiln with fossil fuels and an appropriate mix of waste chemicals, depending on their properties. There are various designs of cement kilns, but modern ones often consist of long rotary kilns which are not dissimilar to dedicated toxic waste incinerators except that their operating temperature is higher and the residence time of fuel and material at these high temperatures is often longer than in dedicated incinerators.

There are reservations about the applicability of cement kilns, but there is also interest in monitoring the progress. Cement kilns are increasingly used for treatment of hazardous waste. Cement kilns for hazardous wastes use blending platforms that ensure proper mixture of the various components so that a low chlorine content 1-2 % maximum is ensured. For HCH-waste with 50% chlorine composition a large dilution has to be performed. Careful selection, control of substances and continuous supply (chlorine) of waste entering the kiln is needed<sup>5</sup> (Karstensen, 2013).

Additionally, they tend to have less sophisticated emission control equipment and cannot accept materials for incineration, which may contaminate or alter the properties of the cement being produced. Therefore, the waste that they can burn can only have a low chlorine content.

# 3.3. Physico-chemical treatment methods for waste, soil and water remediation and decontamination.

The physical remediation methods separate the contaminants from the soil matrix or water by using physical differences between the soil/water matrix and contaminant (e.g. volatility) or between the contaminated and uncontaminated soil particles (e.g. density). The chemical remediation methods destroy, fix or concentrate the contaminants by using chemical reactions. Some of these methods can be used only <code>ex situ</code> and others both <code>ex situ</code> and <code>in situ</code>.

The physical-chemical methods for the removal of lindane include e.g. the use of adsorbents, nanoparticles and chemical dechlorination.

\_

<sup>&</sup>lt;sup>5</sup> Cement Kilns firing Hazardous Waste. Booklet 3. Stockholm Convention. www.pops.int/documents/.../Book%206%20Cement%20Kilns.doc

# 3.3.1. Base Catalysed Dechlorination (BCD) (Waste treatment)

Base Catalysed Dechlorination/decomposition (BCD) is a chemical reaction process that can be used for dehalogenation or decomposition of a range of chlorinated and non-chlorinated persistent organic pollutants (IHPA, 2009e). The method was originally developed by the USEPA. The BCD process involves treatment of liquid and solid wastes in the presence of an alkaline reagent mixture consisting of a high boiling point hydrocarbon and a proprietary catalyst. The mixture is heated at a temperature suitable for the decomposition reaction to take place. The residues produced from decomposition of heteroatomic compounds are carbon, and sodium salts of anions liberated during the complete decomposition reactions. The BCD process can involve direct dehalogenation or decomposition of the waste material, or it can be linked with a pretreatment step such as thermal desorption to remove and collect the contaminants so that a smaller volume needs to be treated by the BCD process (IHPA, 2009e).

IHOBE, the Society of Environmental Management of the Basque Government, with considerable help from the Cohesion Funds, ended in 2001 the removal of some 4,000 tonnes of pure lindane waste and its treatment by BCD process. This experience was framed in a LIFE project (1994) with the main objective of designing a demonstration plant for the treatment of lindane waste using the BCD process. The aim was to demonstrate the feasibility on a real scale of converting HCH into commercial trichlorobenzene. In short, the treatment plant eliminated or irreversibly transformed the pure lindane by the BCD process, which destroys HCH at a temperature of 150° by means of a chemical reaction that converts it to sodium chloride (common salt), trichlorobenzene (TCB) and water. The research allowed the efficiency of the reaction to be maximised to attain a conversion rate of 99.9995% on a throughput of one tonne per hour. At Barakaldo, in its two years of operation before it was decommissioned in 2001, the station eliminated 3,200 tonnes of pure HCH. This process permitted the recycling of 1,074 tonnes of TCB, distilled and commercialized as a primary material for the chemical industry without the difficulties associated with other methods of production. Likewise, the salt resulting from the conversion of the HCH was purified and used for the production of brine; for every kg of lindane 625 gr of trichlorobenzene and 300 gr of brine are obtained. The residue was transferred to the isolation zones.

According to data from IHOBE, around 1,000 tonnes of trichlorobenzene were sent to India, around 8,000 tonnes of brine were derived to properly controlled collectors, while around 300 tonnes of byproducts were collected and deposited into the security cell of Barakaldo. Another 92 tonnes of waste produced in the decontamination process have been sent to an Authorised Hazardous Waste Manager.

The Barakaldo treatment plant has been the first BCD plant to treat lindane (El País, 2001). Later, BCD has also been used in the treatment of lindane contaminated waste and soil in a remediation project of an old pesticide production site in Spolana, the Czech Republic, where a fully-fledged depollution plant was constructed to allow 35,000 tonnes of waste to be treated on site (Holoubek et al., 2011; SE, 2006). The technology has also been used at full-scale to treat other chlorinated and non-chlorinated contaminants in other countries such as Australia, Japan and Mexico. The cost estimate of 1,400 to 1,700 euro per tonne (1.40 to 1.70 euro per kg) is for the year 2004 and is based on information from IHPA (2009e).

# 3.3.2. Gas-Phase Chemical Reduction (GPCR) (Waste treatment)

Gas-phase chemical reduction technology is a process designed to destroy chemical agents. The process uses hydrogen and steam at elevated temperatures (up to 850 °C) and normally atmospheric pressure to transform organic wastes into less toxic materials. The overall process requires a high temperature reaction vessel, where the chemical reduction occurs, followed by a gas scrubbing train to remove inorganic by-products. The process also includes

provisions for removing other by-products and regenerating hydrogen gas through steam reforming. Water is used as quench to decrease the gas temperature and adsorb water-soluble products, including HCl. These and other acidic products are further scrubbed by caustic scrubbers. A heavy-oil scrubber can be used in the scrubber train to remove some hydrocarbons (NRC, 1996). Cooled, scrubbed gas from the process can be reused as a fuel for plant components, or consumed in a burner (IHPA, 2009b).

In the case of soil and sediment treatment, contaminants are first desorbed from the solids using a thermal desorption device (of which there are many proven and available worldwide). The gas containing the contaminants is then condensed, the water removed, and the remaining concentrated contaminant liquid fed to the preheater and GPCR reactor as a contaminant concentrated liquid waste feed (IHPA, 2009a,b).

A commercial GPCR system operated in Australia for more than 5 years, treating more than 2,500 tonnes of PCBs, HCB, DDT and other POPs. Destruction efficiencies of 99.9999 % were obtained for these contaminants with this system (IHPA, 2009b). In Japan a semi-mobile GPCR plant for the treatment of PCB wastes has been in operation since 2003 (Ecologic, 2016). The GPCR method has also been used to treat lindane contaminated waste (IHPA, 2009b).

# 3.3.3. Non-base mediated dechlorination processes (Copper Catalysed dehalogenation; Fly Ash Catalysed Destruction (Hagenmaier Process); Sodium Reduction) (Waste treatment)

Non-base mediated dechlorination techniques include methods such as copper catalysed dehalogenation, fly ash catalysed destruction and sodium reduction. The novel non-combustion technology called Copper Mediated Destruction (CMD) was recently developed and patented. The principles, experimental parameter and trial experiments of the copper mediated destruction method (CMD) were recently presented for polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs), organochlorinated pesticides (OCPs, such as DDTs and metabolites, HCHs, PCPh, PCBz). This technique has been used in Czech Republic to treat several chlorinated contaminants, including HCH (ProjectFOKS, 2009).

The advantage of non-base mediated dechlorination techniques such as copper catalysed dehalogenation and fly ash catalysed destruction is that the risk of formation of PCDD/PCDFs from precursors is lower compared to base mediated processes. However, the fate of condensation reactions should also be assessed for the destruction of precursor containing waste (Weber, 2004).

# 3.3.4. Plasma Arc (Waste treatment)

A plasma arc operates on principles similar to an arc-welding machine, where an electrical arc is struck between two electrodes. The high-energy arc creates high temperatures ranging from 3,000 degrees to 7,000 degrees Celsius. The plasma is highly ionized gas. The plasma arc is enclosed in a chamber. Waste material is fed into the chamber and the intense heat of the plasma breaks down organic molecules into their elemental atoms. In a carefully controlled process, these atoms recombine into harmless gases such as carbon dioxide. Solids such as glass and metals are melted to form materials, similar to hardened lava, in which toxic metals are encapsulated. With plasma arc technology there is no burning or incineration and no formation of ash. There are two main types of plasma arc processes: plasma arc (or DC) melter and plasma torch. Plasma arc melters have a very high destruction efficiency. The high temperatures produced by the arc convert the organic waste into light organics and primary elements (CPEO, 2010).

Concerns have been raised regarding the reliability of plasma torch technology. The water-cooled copper torch must be replaced periodically to prevent burn-through at the attachment point of the arc and a subsequent steam explosion due to rapid heating of the released cooling water (CPEO, 2010).

The "in-flight" plasma arc PLASCON technology has been operating commercially since 1992 treating several POP pesticides and PCBs (IHPA, 2009d). To date there are 10 commercial plants operating with licences from the Victorian and Queensland EPA's in Australia, the UK EPA, the USA EPA, the Mexican EPA and the Japanese Ministry of the Environment (IHPA, 2009d).

# 3.3.5. Thermal desorption (Soil treatment)

Briefly, the thermal de-sorption consists in heating the soil to about 400-600°C (depending on the boiling point of the contaminant) causing the contaminants to evaporate, which are then passed to an afterburner where they are conventionally incinerated. Thermal desorption can be carried out *ex situ* in specialised treatment plants, but *in situ* systems have been developed, too (Krügger, 2016). The advantage of thermal desorption is that it can be used to various soil types and to extract a wide range of contaminants, e.g. PAHs, chlorinated hydrocarbons and different pesticides (Agassi et al. 1998). Furthermore, the treated soil can be reused e.g. in civil works. However, thermal desorption requires sophisticated technologies to avoid the formation and release of dioxins and furans during the final incineration of the contaminants in gas phase. Thermal desorption systems require treatment of the off-gas to remove particulates and contaminants. Particulates are removed by conventional particulate removal equipment, such as wet scrubbers or fabric filters. Contaminants are destroyed in a secondary combustion chamber or a catalytic oxidizer or are removed through condensation followed by carbon adsorption.

As an example, an improved in-situ method (SOC, 1993) for the remediation of soil containing organic or semi-volatile inorganic contaminants is explained below. This process is especially useful for the remediation of soils contaminated with non-volatile and semi-volatile organics, such as diesel fuel, aviation and jet fuel, crude oil, PCBs and pesticides and semi-volatile inorganics such as metallic mercury. This in-situ thermal desorption system utilizes a perforated or slotted pipe buried in the soil below the depth of contamination in the soil. The surface of the soil is covered with a layer of permeable insulation (to conserve heat and to provide a gas migration path on top of the soil) and a layer of impermeable material above the insulation.

A vapour recovery/treatment system induces a vacuum between the impermeable layer and the soil surface (e.g., a vacuum pump or an induced draft fan) and a treatment system for the contaminated vapour (e.g., a cold trap, carbon adsorption, or incineration). Fuel and compressed air are fed into a pressurized combustion chamber and combusted. The combustion products flow into the buried pipe and are distributed through the contaminated soil. Heat from the pressurized combustion products causes the organic contaminants within the soil to vaporize, pyrolyze, decompose, or react with oxygen. Contaminants and their byproducts are swept away by the combustion products into the vapour recovery/treatment system.

Thermal desorption has been used in the clean up of soils contaminated with HCH and other chlorinated compounds since the 1980s in the Netherlands (van Hasselt et al. 1998), Nearly 300,000 tonnes of HCH-contaminated soils have been successfully treated mainly with thermal desorption and partly with soil washing (Vijgen, personal communication). For example, 60,000 tonnes of soil from a former pesticide production site heavily contaminated

with HCH, dioxins and furans was treated in a thermal treatment plant in Rotterdam in 1996 (Agassi, 1998). High removal efficiencies (>99%) of lindane were obtained: initial concentrations of HCH up to 1500 mg/kg soil were reduced to 0.01 mg/kg. Initial concentrations of dioxins and furans of 20,000 ng  $TEQ^6$ /kg were reduced to 100 ng TEQ/kg after the treatment. The average concentration of dioxins and furans in the smokestack was 0.01 ng  $TEQ/m^3$ , which is far below the target value of 0.1 ng  $TEQ/m^3$ . Thus, high removal efficiency for HCH was achieved and possible dioxin and furan emissions from the afterburner were efficiently controlled.

In Spoland Neratovice (Czech Republic) large quantities of soil have been successfully treated with a combination of thermal desorption and Base catalysed dechlorination (BCD). Thermal desorption was used to extract the pure waste from the soils and BCD technology to treat the pure waste (Vijgen, personal communication).

Araújo et al. (2016) have studied the effect of temperature and heating time on the efficiency of thermal desorption of HCH from contaminated soil in laboratory conditions. The results showed that  $\gamma$ gamma-HCH was efficiently removed from the initial concentration of 0.96  $\mu$ g/g soil to 0.01  $\mu$ g/g soil when heating the soil to 200 °C during 30 minutes. At 350°C the removal of this isomer was significant already after six minutes of heating. For the other isomers, higher temperatures and longer heating times were required to obtain a significant removal form the soil. Beta-HCH showed significant removal only after heating the soil to 350°C for 96 hours and the concentration remained at 0.2  $\mu$ g/g soil even after 480 hours of heating.

## 3.3.6. Solvent extraction (Soil treatment)

Solvent extraction can be used to dissolve and extract the contaminants from the soil or other medium in which they are held. The solvents can be reused while the contaminants are destroyed or safely contained. The method usually consists of four steps: the extraction of the contaminant with the solvent; the separation of the extracting agent and the treated matrix (soil/sediment/water); the removal of residual amounts of the solvent from the treated matrix; and the recovery of the solvent for reuse. Often the soil needs to be pretreated (e.g. crushing and homogenisation) before the solvent extraction can be applied. Factors that influence the efficiency of the method include e.g. the type of solvent used, the soil/solvent ratio, the concentration of the contaminant and the characteristics of the soil (or other matrix).

Solvents used in the extraction of lindane include e.g. hexane, isopropanol and acetone. For example Salas et al. (1999) observed in a bech scale study a reduction of over 90% of HCH from soil samples when 30 g of solvent (methanol, isopropanol, acetone or MEK) was added to 10 g of soil, and the test vessels were shaken for five minutes. If the extraction step was conducted two or three times it was possible to obtain a residual HCH concentration in soil of 1 ppm and a removal efficiency above 99%.

Boron trifluoride-methanol has been shown by Westcott and Worobey (1985) to be a useful reagent used as a pre-treatment for the extraction of lindane residues from soil. The boron trifluoride-methanol pre-treatment resulted in a 20-70% increase in the lindane extracted from field-weathered soils compared to extraction with hexane-acetone. The lindane that was

\_

 $<sup>^6</sup>$  The toxic equivalency of a mixture is defined by the sum of the concentrations of individual compounds ( $C_i$ ) multiplied by their relative toxicity (TEF). (**TEF**) expresses the toxicity of dioxins, furans and PCBs in terms of the most toxic form of dioxin, 2,3,7,8-TCDD

unextractable by hexane-acetone, but was extractable with the boron trifluoride-methanol treatment, was confirmed by the chemical and mass spectral method.

About 70,000 tonnes of HCH contaminated soils have been successfully treated in the Netherlands in a full-scale soil washing plant, which proved to achieve HCH removal efficiency of more than 99.7% (Cuyten, 1999).

# 3.3.7. Remediation by nanoparticles (Soil and water treatment)

Nanoparticles are particles that have one or more external dimensions at the nanoscale. The use of engineered nanoparticles in the remediation of contaminated soils and waters is a growing area of research, and some applications are already in use (Mueller, and Nowack 2009). Nanoremediation may offer a more cost-effective remediation option for lindane contaminated soil and groundwater than more conventional methods, e.g. chemical degradation and physical adsorption due to the high surface area, and thus high reactivity, of nanoparticles and the possibility to use them *in situ*. However, the fate and effects of engineered nanoparticles in the environment, especially in soil, as well as their potential human health effects are not yet well known and therefore more research is needed before *in situ* nanoremediation can be used more widely.

One of the most investigated nanoparticle used in environmental remediation is the Nano Zero Valent Iron (nZVI). Some authors (e.g. Song and Carraway 2005) have indicated that this nanoparticle can increase the degradation rate of contaminants. The use of metals as a remediation agent is based on a widely known reduction-oxidation chemical reaction that uses a neutral electron donor (a metal) to chemically reduce an electron acceptor (a contaminant). Elliot et al. (2009) studied the use of nZVI in the degradation of lindane in water. In their study, lindane (at an initial concentration of 7.5 mg / L) disappeared from the aqueous solution within 24 h in the presence of nZVI concentrations ranging from 0.015 to 0.39 g/L, whereas approximately 40% of the initial lindane dose remained in solution after 24 hours in the presence of 0.53 g/L of larger microscale iron particles. No non-halogenated organic end-products were detected in the experiment, but trace concentrations of benzene were detected. Chloride was detected as a stable end-product, demonstrating the reductive degradation of lindane. In another study, Singh et al. (2001) observed that nZVI enhanced the degradation of lindane in spiked soil. Lindane at an initial concentration of 1.6 g/L. completely disappeared from spiked soil within 24 hours at a nZVI concentration of 1.6 g/L.

The coating of iron nanoparticles with another catalytic metal has been observed to further enhance the degradation efficiency. For example, in a study by Nagpal et al. (2010) lindane in an aqueous solution at an initial concentration of 5mg/L completely degraded in five minutes by Fe-Pd bimetallic nanoparticles present at a concentration of 0.5 g/L, while only around 65-70% of lindane was degraded by Fe-nanoparticles (0.5 g/L) in the same period of time. The concomitant increase of chloride ion observed in the study confirmed that the removal of lindane was mostly by degradation and not by other processes e.g. adsorption to surface of the nanoparticles. Joo and Zhao (2008) observed that the degradation rate of lindane was progressively enhanced as the Pd content of Fe-Pd bimetallic nanoparticles increased from 0.05% to 0.8% of Fe, and the catalytic effect of Pd was more significant under anaerobic condition.

There is no information on the application of this technique for treatment of lindane at pilot scale.

# 3.3.8. Sorption by activated carbon (Water treatment)

The adsorption process is recognized as the most efficient approach in wastewater treatment since it can remove different types of organic pollutants and has a simple design and easy

operation (Foo and Hameed, 2009). Among a large variety of adsorbents, activated carbon (AC), is being widely used in developed countries in environmental pollution control of aqueous samples due to its large surface area, high adsorption capacity, internal porous structure and selective adsorption (Babel and Kurniawan, 2003; Cheremisinoff and Ellerbush, 1979; Mattson and Mark, 1971; Plllar et al., 1992; Ucer et al., 2006).

The effectiveness of different powdered activated carbon in the removal of lindane and other HCH-isomers from water has been tested. For example, the adsorption capacity of activated agricultural waste date stones was compared with a commercial AC (Norit) (El Kady et al., 2013). The adsorption of lindane was found to be at its maximum (98.6%) under neutral conditions (pH 7.0). The maximum adsorption of lindane onto the ACs was achieved at room temperature ( $25^{\circ}\text{C} \pm 1$ ).

Hassan et al. (2009) used powdered activated carbon, obtained from the apricot stone, as an inexpensive and effective adsorbent for the removal of lindane and malathion from wastewater. The authors observed a 95.52% adsorption uptake for lindane at  $30^{\circ}$ C. Adsorption uptake (%) was very low at pH 4, increased rapidly at pH 5.5 and reached its maximum at pH 6.0. This was also observed by Vinod et al., (2002), where the maximum removal of lindane took place at pH 6.0 and sorption equilibrium was reached after six hours. The surface area of the activated carbon was  $642 \text{ m}^2/\text{g}$ .

Kouras et al. (1998) observed in their laboratory study that powdered activated carbon at concentrations higher than 20 mg/L is capable of reducing the concentration of lindane from  $10~\mu g/L$  to  $0.1~\mu g/L$  in aqueous solutions within one hour contact time. In contrast to the above mentioned studies, they did not find any significant difference in the lindane adsorption efficiencies of the activated carbon at pH range 4-10. However, the authors noted that at lower pH values the amount of organic matter (e.g. humic and fulvic acids) present in the water may be higher, which can lead to a competition in the adsorption of different organic compounds onto the activated carbon, and hence the adsorption of HCH could decrease.

Activated carbon has been used in the treatment of groundwater or landfill leachates contaminated with HCH in the EU, e.g. in Italy, Germany, the Netherlands, Poland and Spain (see section 2).

# 3.3.9. Super Critical Water Oxidation (SCWO) (Water treatment)

Super Critical Water Oxidation (SCWO) is process in water at temperatures and pressures above a mixture's thermodynamic critical point. The process usually operates in a temperature range of 450–600°C and pressure range of 24–28 MPa. The aqueous waste stream containing the organic is pressurised and preheated to reactor conditions. Then, behaviour of water as a solvent is "reversed" so that chlorinated hydrocarbons become soluble in the water, allowing single-phase reaction of aqueous waste with a dissolved oxidizer. The one-phase mixture of water, organic and oxidant enters the reaction zone, where both organic compounds and oxygen are completely soluble, and the temperature is high enough that free radical oxidation reactions proceed rapidly. The organic oxidises rapidly and completely (destruction efficiency >99.99% with residence times less than one minute) to CO<sub>2</sub> and H<sub>2</sub>O (Veriansyah and Kim, 2007)

SCWO has been shown effective in the treatment of toxic chlorinated chemicals such as polychlorinated biphenyls (PCBs) (Anitescu and Tavlarides, 2005), the pesticide DDT (Modell, 1990), and dioxins (Thomason et al., 1990) among other compounds. Compounds which are problematic to recycle or dispose due to the formation of hazardous by-products and residues such as the polymer polyvinylchloride (PVC) and the chlorocarbon - hexachlorocyclohexane

and gamma-hexachlorocyclohexane, are completely oxidised without hazardous by-product formation (Hirth et al., 1998).

SCWO can be classified as green chemistry or as a Clean Technology. The elevated pressures and temperatures required for SCWO are routinely encountered in industrial applications such as petroleum refining and chemical synthesis.

Commercial SCWO systems are operated in Japan, the US, the UK, Korea, and France (IHPA, 2009c).

#### 3.3.10. Photocatalysis (Water treatment)

The acceleration of a chemical transformation by the presence of a catalyst with light is called photocatalysis. Several studies have investigated the photocatalytic degradation of contaminants in water environments. The most widely used photocatalyst is the titanium dioxide nanoparticle ( $TiO_2$ ) due to its high photochemical stability, high photoactivity, acceptable band gap energy and low cost (Kabra et al. 2004). To avoid free nanoparticles ending up in water,  $TiO_2$  particles are usually immobilised on a substrate e.g. by dip coating, spray coating or electrophoretic coating. Another option is to use  $TiO_2$  thin films on glass substrates.

 $TiO_2$  particles absorb only a narrow band in the UV region of the solar spectrum. However,  $TiO_2$  particles can be doped with another semiconductor (e.g. a noble metal or nitrogen) to increase the efficiency of the photocatalyst and to enable the use of a wider spectrum of wave lengths (e.g. visible light).

The photocatalytic degradation of lindane by  $TiO_2$  particles in water has been studied. Zaleskaa et al. (2000) reported a maximum 77% degradation of lindane at an initial concentration of 40 ppm in an aqueous solution with  $TiO_2$  and after 150 min irradiation under UV-light. Senthilnathan and Philip (2010) observed a 100% degradation of lindane in 120-450 minutes at initial lindane concentrations of  $8.62 \times 10^{-5}$  to  $5.17 \times 10^{-4}$  mmol/L using N-doped  $TiO_2$  under visible light. GC-MS analysis revealed that lindane was completely degraded and no intermediate was observed at the end of the analysis. The rate of degradation of lindane gradually decreased with an increase in the initial pesticide concentration.

Although most of the research on photocatalysts have been carried out for water environments, there are some studies that have investigated the photocatalytic degradation of contaminants in surface soils. For example, Zhao et al. (2007) studied the use of TiO2 and montmorillonite composite photocatalyst in the degradation of lindane spiked in soils and the effect of soil pH in the degradation. Photodegradation rate increased with the soil pH. At pH 10.3, 76% of lindane was degraded within two hours and over 90% of lindane was degraded after 12 hours. At pHs 8.2 the degradation rate was slightly lower and at pH 4.6 significantly lower. The detected photodegradation intermediates included pentachlorocyclohexene, trichlorocyclohexene, and dichlorobenzene. After nine hours of irradiation these substances were not detected in the samples anymore, suggesting that the photodegradation intermediates were gradually degraded.

There is no information on the application of this technique for treatment of lindane at pilot scale.

#### 3.3.11. Biocatalytic dechorination (Water treatment)

One option for the elimination of lindane is a reductive dechlorination using biocatalysts. For example, Mertens et al. (2007) have demonstrated that biogenic Pd nanoparticles ('bio-Pd')

can be used as catalysts for the dechlorination of lindane. Bio-Pd are palladium(0) nanoparticles formed by bacteria (e.g. *Shewanella oneidensis*). The advantage of bio-Pd compared to commercial powder Pd, which is often used as a catalyst in dechlorination processes, is that the surface area of the bio-Pd is higher and thus it has a higher reactivity. In the study by Mertens et al. (2007) where the bio-Pd nanoparticles were immobilized in a dialysis membrane in a fed-batch process, a removal percentage of 85-98% of gamma-HCH in aqueous solution (initial concentration 10 mg/L) was achieved within 24 hours.

Hennebel et al. (2011) studied the use of bio-Pd nanoparticles encapsulated in polymer beads in the removal of low concentrations of HCH isomers (total HCH isomer concentration around 5  $\mu$ g/L) from groundwater. In their pilot scale study, 29% and 75% of HCH were removed applying a residence time of four and eight hours respectively for the water flow in the reactor. The different HCH isomers showed varying removal percentages with a maximal removal of gamma-HCH (75% and 90%). However, the authors noted that the process should be further improved to obtain removal efficiencies comparable to those observed for activated carbon (around 98%).

There is no information on the application of this technique for treatment of lindane at pilot scale.

## 3.3.12. *In situ* chemical oxidation (Soil and groundwater treatment)

In situ Chemical Oxidation (ISCO), is an environmental remediation technique used for soil and/or groundwater remediation to reduce the concentrations of targeted environmental contaminants. ISCO is accomplished by injecting or otherwise introducing strong chemical oxidizers directly into the contaminated medium (soil or groundwater) to destroy chemical contaminants in place. It can be used to remediate a variety of organic compounds, including some that are resistant to natural degradation.

The following compounds are the oxidants most commonly used in this process:

Permanganate: Permanganate is used in groundwater remediation in the form of potassium permanganate (KMnO4) and sodium permanganate (NaMnO4). The biggest difference between the two chemicals is that potassium permanganate is less soluble than sodium permanganate (Amarante, 2000).

Fenton's Reagent: Fenton's reagent is basically a mixture of ferrous iron salts as a catalyst and hydrogen peroxide. When the peroxide is catalyzed by soluble iron it forms hydroxyl radicals (·OH) that oxidize contaminants such as chlorinated solvents, fuel oils, and BTEX (Amarante, 2000).

Persulphate. The sulfate radical reacts with the organic compounds to form an organic radical cation. Conversely, the sulfate radical does not react as much in compounds that contain electron attracting groups like nitro (-NO2) and carbonyl (C=O) and also in the presence of substances containing chlorine atoms. Also, as the number of ether bonds increases, the reaction rates decrease (Tsitonaki et al., 2010).

The Department for Environment of the Aragón Government is currently testing the decontamination of the groundwater through chemical oxidation, in the frame of an EU Life Plus project named DISCOVERED LIFE- 2012(GA, 2016a). This demostration project, based on chemical in situ oxidation (ISCO) with alkaline activation, aims to design, install and operate a prototype pollution mitigation system that will be used to restore water quality in

those aquifers contaminated with lindane in the area of Sabiñánigo (Huesca).

One of the main tasks of the project is to demonstrate that the high rates of pollutant destruction achieved in the laboratory may be also achieved on the field. For that purpose, an ISCO pilot test to mobilize and oxidize the pollutants from the DNAPL that could not be pumped out and are still trapped in the fractures of the soil will be developed. The aim is to reduce the existing pollution load in the aquifer and to turn it into less harmful or innocuous compounds.

In relation to the project's full scale implementation study, the key result will be an assessment of the technical and economic feasibility of scaling up the pilot system and testing the viability of the developed techniques regarding management of the DNAPL. DNAPL treatment and pollutant plume, as well as cost/benefit ratios and a socio-economic impact assessment. This knowledge will inform a set of associated methodological guidelines.

Although the project is developed to the Bailín site it is expected that it could be transferred elsewhere where similar problems exist. The project, that started on 1st of January, 2014 is ongoing and expected to be finished by 30th of June, 2017

# 3.4. Biological methods: soil and water bioremediation

Biological treatment methods of contaminated soils and waters involve the use of microorganisms or vegetation. Microorganisms and plants can destroy contaminants or transform them to less hazardous chemicals, as well as extract and accumulate them.

The advantage of biological methods is that they are environmentally-sound, low cost methods and they can be used *in situ*. However, the efficiency of these methods in field conditions may still be quite limited as there are many factors that affect the processes. Therefore, further research, especially field studies, is needed to better understand the factors affecting the bioremediation and to improve their efficiency.

# 3.4.1. Microbial degradation

Certain microorganisms are able to digest some toxic chemicals and this is often an important route by which pesticides are degraded once applied in the field. By selecting the most effective microorganisms and creating ideal environmental conditions for them, it is sometimes possible to accelerate the degradation process significantly.

Bioremediation is being investigated as a way of decontaminating soils rather than destroying stocks of chemicals. It is a relatively undeveloped technology, which currently seems limited to a few chemicals and specific conditions. It is an area, which will benefit from further research to develop widely applicable systems to assist in site decontamination.

Bioremediation by microorganisms can be categorised into two different approaches: biostimulation and bioaugmentation. Biostimulation means the modification of the environmental conditions (e.g. addition of limiting nutrients or oxygen, control of pH) to support the growth and activity of the autochthonous microbial population already present in the site. Bioaugmentation involves the addition of living microbial cells capable of degradation. These cells can be enriched cultures that have been originally isolated from the contaminated site to be treated or they can originate from other contaminated sites. A combination of both approaches may also be used. The choice of the approach depends on the properties and characteristics of the contaminated site and its microbial population, e.g.

on the presence of adequate microorganisms capable of degrading, the bioavailability of the contaminant, the availability of nutrients, pH and other environmental factors.

A lot of research has been done on the bacterial degradation of lindane and other HCH-isomers. Both aerobic and anaerobic bacteria have been found to be able to degrade these contaminants (see Table 17). The key reaction during the microbial degradation of halogenated compounds is the removal of the halogen atom. During this step, the halogen atoms, which are usually responsible for the toxic and xenobiotic character of the compound is usually replaced by hydrogen or a hydroxyl group. Aerobic degradation proceeds through several intermediate degradation products, e.g. penta- and tetrachlorocyclohexenes (PCCH and TCCH), tri- and dichlorobenzenes (TCB and DCB), and can end up in complete mineralisation (reviews by Phillips et al., 2005, Lal et al., 2010). Anaerobic degradation of HCH-isomers usually results in the fomation of benzene and chlorobenzenes as end products (Lal et al., 2010).

Table 17. Examples of bacteria capable of degrading lindane and other HCH-isomers.

Degradation mode	Bacteria	Reference
Aerobic processes	Micromonospora sp	Fuentes et al. 2010
	Streptomyces sp	Fuentes et al. 2010
	Pseudomonas sp.	Nawab et al. 2003
	Sphingobium sp.	Jagnow et al. 1977
	Microbacterium sp	Manickam et al. 2006
	Pandoraea sp.;	Okeke et al. 2002
	Sphingomonas sp	Mohn et al, 2006; Lal et al, 2010
Anaerobic processess	Clostridium sp.	MacRae et al. 1969
	Methanogenic enrichment culture	Middeldorp et al. 1996
	Sewage sludge	Buser and Muller 1995

The gram negative bacteria belonging to the Sphingomonadaceae family are among the most studied species (review by Lal et al., 2010). The genes encoding the HCH degradation enzymes of these bacteria, the so-called *lin*-genes, have been cloned, sequenced and characterised (Nagata et al 1999; Mohn et al., 2006; Lal et al., 2010).

In recent years there has been research on the use of actinobacteria (e.g. *Streptomyces* species) in the removal of lindane from soils (e.g. Benimelli et al., 2008, Fuentes et al., 2010). Actinobacteria are a diverse group of gram positive bacteria which form an important part of the soil microbial community. These bacteria are less studied than the gram negative bacteria but they may offer an efficient method for the bioremediation of lindane and other pesticides, contaminated soils due to their metabolic diversity and specific growth characteristics (Shelton et al. 1996).

Several cyanobacteria have also been observed to degrade lindane and HCH in water (Kuritz and Wolk, 1995). The advantages of these photosynthetic bacteria in the bioremediation of

contaminated waters are that they have low nutrient requirements and being autotrophic they can produce a large biomass without carbon-source additions.

Besides bacteria, other microorganisms, such as fungi, can also degrade HCH isomers. Especially different white rot fungi, e.g. *Phanerochaete sp*, (Mougin et al., 1997) *Trametes sp*. (Singh and Kuhad, 1999) and *Pleurotus sp*. (e.g. Mohapatra and Pandey, 2015), but also some other fungi, e.g. *Conidiobolus* (Nagpal et al., 2008), have been demonstrated to be capable of degrading different HCH isomers. Fungi are able to degrade contaminants such as lindane due to their production of non-specific extracellular enzymes (e.g. peroxidases, phenol oxidases, manganese and lignin peroxidase, laccases) that catalyze a wide range of oxidation reactions, leading to the breakdown of organic compounds (Dashtban et al., 2010).

The complete mineralisation of HCH isomers has been reported for some microorganisms, e.g. *Sphingobium* bacteria (Nagata et al., 2007) and for some white-rot fungi (Mougin et al. 1997; Singh and Kuhad 1999). However, often a consortia of different microorganisms is beneficial for an efficient and complete degradation of lindane and other HCH-isomers. This is because most species are not capable of degrading all the HCH-isomers or their transformation products (Phillips et al 2005).

There are several factors that affect the microbial biodegradation of contaminants. One important factor is the bioavailability of the contaminants to the degrading microorganism (Phillips et al., 2005). Lindane and HCH-isomers have high absorption properties and thus limited availability in many soil types. This may lead to lower degradation rates in field conditions compared to laboratory conditions.

The concentration of lindane and other HCH-isomers may also affect the biodegradation rate. When concentrations are too high, the contaminants may have toxic effects on microorganisms. In contrast, low contaminant concentration may prevent the induction of microbial degradation enzymes. For example, Okeke et al. (2002) observed in a study on lindane removal by *Pandoreae* sp in liquid and soil slurry that the rate of lindane removal increased with increasing concentrations up to 150 mg/L but declined at 200 mg/L, after four to six weeks of incubation. Benemelli et al. (2008) found a similar pattern in their study on lindane removal by *Streptomyces* sp in spiked soil. With initial lindane concentrations of 100, 150, 200, and 300  $\mu$ g/kg, the percentage of the pesticide removal after a four-week incubation was 29.1%, 78.0%, 38.8%, and 14.4% respectively. However, in this study, it was observed that the growth of *Streptomyces* sp was not significantly affected by the concentration of lindane. Therefore, the authors suggest that as the soil contained readily available organic nutrients that the bacterium may prefer for growing, it would be possible that the pesticide could be used as a secondary substrate source (co-metabolism).

The most important environmental factors affecting the degradation rate of microorganims include pH, temperature, soil moisture-content and nutrient availability as these can hinder the growth of the degraders. The optimal pH depends on the species. For example, the degradation of HCH-isomers by Streptomyces sp. has been observed to be highest around pH 7 (Sinelli et al., 2016), for Pandoraea sp. the highest degradation rate was observed at initial pH 8 (Siddique et al. 2002,). The optimal temperature for microbial degradation of lindane seems to be around 30 °C (Siddique et al., 2002, Benimelli et al., 2007, Sinelli et al. 2016). However, Zheng et al. (2011) demonstrated that some *Sphingobium* strains can efficiently degrade lindane and other HCH-isomers also at low temperatures (4°C).

Microbial bioremediation has been used in the remediation of some lindane contaminated sites in the EU, e.g. in the Netherlands (Bouwknegt, personal comment) and Germany

(Richnow, personal comment). Langenhoff et al. (2013) conducted a field experiment on the use of an in situ bioscreen to enhance the anaerobic biodegradation of HCH in the groundwater in an old HCH production site in the Netherlands. Bioscreen means a local zone in soil that has a high retention capacity and increased microbial degradation activity. When groundwater flows through the bioscreen zone, the concentration of contaminants is reduced. In the Dutch contaminated site, the typical concentrations of HCH in groundwater ranged from 100 to 2000  $\mu$ g/L. The contaminated groundwater flowed towards a freshwater canal, and therefore, measures were needed to protect the canal from HCH-contamination. Biodegradation of HCH was observed to already take place in the site but it was not sufficiently efficient to prevent the HCH entering the canal.

The bioscreen was created by injecting an anaerobic infiltration solution containing methanol as an electron donor and nutrients to soil in order to create an anaerobic activated zone where the biodegradation of HCH isomers, especially of the most recalcitrant - beta and epsilon isomers, was enhanced. After the anaerobic degradation in the bioscreen zone, the groundwater containing the transformation products (mainly benzene and chlorobenzene) was extracted and passed through an already existing on-site water treatment plant where aerobic degradation took place. Aerobic conditions were necessary for an efficient degradation of the transformation products. The concentration of HCH in the groundwater decreased from 600  $\mu$ g/L to the detection limit of individual HCH-isomer concentrations (0.01  $\mu$ g/L) after one year or operation. Furthermore, the results of the experiment suggested that the enhanced biodegradation rate of HCH in groundwater increased the desorption rate of HCH from soil to groundwater resulting in higher overall HCH degradation.

Although efficient microbial degradation of lindane and other HCH-isomers has been demonstrated in several laboratory studies, the extent and rate of degradation in field conditions may be different (e.g. Anupama and Paul 2007) due to the various factors affecting microbial activity and biodegradation (Phillips et al. 2005). There are only a few field studies on the microbial remediation of lindane contaminated soils and waters, and therefore more research is needed. Furthermore, most of the soil biodegradation studies have been conducted at relatively low HCH-concentrations and there are only a few studies available on biodegradation of HCH at higher concentrations that are relevant for many old productions or dumping sites of HCH and lindane (Phillips et al. 2005).

# 3.4.2. Biosorption microbes

There are some reports on natural microbial species including bacteria and fungi which are capable of removing lindane by biosorption showing low uptake capacity (Tsezos and Bell, 1989); Ju et al., 1997)

A yeast belonging to the soil Basidiomycota family had been isolated from the agricultural fields of maize plants for the removal of medium-high concentrations of lindane from aqueous solutions (Salam and Das, 2013). The obtained dried biomass was ground to fine powder using a grinder and sieved to a constant size  $(100-125 \, \mu m)$ . This biosorbent was designated as native biomass. Among the various pre-treated chemicals tested for surface modifications, citric acid treated *C. sorghi* had an enhanced lindane uptake capacity of about 3-4 folds higher than the native yeast biomass. At acidic pH, the protonation surface functional groups on the biosorbent takes place, and thereby enhances the approach of the negatively charged pesticide molecule on the surface of the biosorbent resulting in increased biosorption. In the present study, the biosorption capacity of native yeast biomass for lindane was highest at pH 3.0. On the other hand, increase in pH above 3.0 resulted in decreased lindane uptake.

Table 18. Lindane biosorption capacity of different adsorbents

Sorbent	Capacity <sub>max</sub>	Reference
R. arehizus	3.622 mg/l	Tsezos and Bell, 1989
Pretreated E.coli	4 mg/l	Ju et al, 1997
Pretreated Powdered activated carbon	1.5 mg/l	Hassan et al, 2009
Fly ash baggase	2 μg/g	Gupta et al, 2002
Compost soil	48.42±1.8 mg/g	Krishna and Philip, 2008
Granular activated carbon	487±72 mg/g	Sotelo et al., 2002
Pine bark	3.17 mg/g	Ratola et al., 2003
Pretreated C. sorghi	100 mg/g	Salam and Das, 2013

#### 3.4.3. Phytoremediation

Phytoremediation involves growing plants in a contaminated matrix in order to remove contaminants or to facilitate their immobilisation (binding/containment) or degradation. Phytoremediation methods can be categorised into the following groups:

- Phytodegradation: the use of plants to uptake, store and degrade contaminants within its tissue.
- Rhizodegradation: the use of plants and symbiotic soil microbes to degrade contaminants in the root zone.
- Phytoextraction: the use of plants to absorb, translocate and store toxic contaminants from a soil matrix into their root and shoot tissue.
- Phytovolatilisation: the use of a plant's ability to uptake contaminants from the growth matrix and subsequently transform and volatilise them into the atmosphere.
- Phytostabilisation: the plant-mediated immobilisation or binding of contaminants into the soil matrix, thereby reducing their bioavailability.
- Rhizofiltration: the use of roots to uptake and store contaminants from an aqueous growth matrix.

The proper selection of plant species plays an important role in phytoremediation. The selected species need to be able to extract or degrade the contaminants of concern and be able to adapt to the local climate and soil characteristics. Other aspects that should be taken into account include the growth rate of the plant, the depth of the plant's root structure, the ease of planting and maintenance as well as whether the plant is native to the area to avoid introducing non-native invasive species. Furthermore, it may be beneficial to use some organic or inorganic amendments (e.g. nutrients, agro- or industrial waste, biochar, humic acids and other organic material) in order to improve the bioavailability of the contaminants as well as to enhance the growth of the plants and the activity of the microorganisms (see review by Wiszniewska et al. 2016).

The majority of research on the phytoremediation of POPs has focused on phytodegradation or phytotransformation (Cherian and Oliveira, 2005; Aken et al., 2010) with limited research using phytoextraction. Research investigating the phytoextraction of pesticides has mainly focused on food crops to extract chlordane and DDT (Whitfield et al., 2010), dieldrin and endrin (Otani and Seike, 2006), PCBs (Ficko et al., 2010) and medicinal plants (e.g. Withania somnifera) known to accumulate lindane (Lunney et al., 2004) from soil.

Rhizodegradation, which is based on the interaction between plants and their symbiotic microbes, has been demonstrated as a promising method to breakdown many organic contaminants from soil. The microbial density and activity in rhizosphere (soil surrounding the roots of plants) are enhanced by the presence of plant roots as they release root exudates (e.g. sugars, alcohols, and acids) that provide food and nutrients for the microbes. Microbial degradation is also aided by the way plants loosen the soil and transport water to the area. In addition, root exudates can also contain extracellular enzymes, which may directly induce the degradation of contaminants (see review by Wiszniewska et al. 2016). Furthermore, in several studies it has been shown that the growth and survival of plants is increased in the presence of rhizospheric microbes (review by Mendes et al. 2013). Therefore, it seems that the combined use of microbial and plant species is a better strategy than microbial mediated or plant mediated remediation alone

The degradation of lindane and HCH has been reported to be faster in the rhizosphere compared to unplanted soil. For example, Abhilash et al. (2011) showed the beneficial effects of the combined rhizoremediation potential of Staphylococcus cohnii in the presence of the tolerant plant Withania somnifera grown in lindane-spiked soil. Withania was grown in garden soil spiked with 20 mg/kg of lindane and inoculated with 100 ml of microbial culture in open conditions. The inoculation of rhizospheric microbe resulted in an enhanced growth of test plants and enhanced dissipation of lindane from the soil (from 43% to 76%). In another study by Abhilash et al. (2013), the biodiesel plant Jatropha curcas was shown to enhance the dissipation of lindane in spiked soil. After 300 days of cultivation, the residual lindane concentration was reduced to 70-90% depending on the initial lindane concentration, whereas in the case of non-vegetated experiments, the dissipation rate was 40-50%. Furthermore, the enhanced dissipation rate in vegetated experiments was positively correlated with their rhizospheric microbial biomass load. Becerra-Castro et al. (2013) found that substrates planted with the leguminous plant Cytisus striatus and inoculated with the bacteria Rhodococcus erythropolis and Sphingomonas sp. showed a higher dissipation of HCH isomers than substrates only inoculated with the two bacteria. Böltner et al. (2008) also reported that Sphingomonas bacteria growth and lindane removal were higher in soil with maize plant roots than in unplanted soil.

There are also some studies available on the phytoextraction of lindane and HCH although this remediation method is more often used for metal contaminants. For example, Dubey et al. (2014) studied the phytoextraction and dissipation of lindane by spinach ( $Spinacia\ oleracea\ L$ ) grown in different concentrations of lindane (5, 10, 15 and 20 mg/ kg). The concentrations of lindane in the root and leaves of spinach growing in four different concentrations reached up to 3.5, 5.4, 7.6 and 12.3 mg/kg and 1.8, 2.2, 3 and 4.9 mg/kg, respectively. The residual lindane in the four test concentrations was reduced to 81%, 76%, 69% and 61% respectively. Furthermore, there was a significant difference in the dissipation of lindane in vegetated and non-vegetated soil. In the study by Abhilash et al. (2013), the accumulation of lindane in  $Jatropha\ curcas$  grown in soils with spiked lindane concentrations of 5, 10, 15 and 20 mg/kg was also measured. The concentration in the plant reached up to 5.42, 10.83, 15.95 and 20.85 µg/g plant dry matter respectively. Maximum accumulation occurred in the root followed by the stem and then the leaves.

There is also information on new patents of transgenic plants, which can degrade HCH into 1,2,4-trichlorobenzene (CSIC, 2016). This potential use of transgenic plants that will be released in the environment will need an environmental risk assessment previous to their use in the environment according to the EU legislation.

Phytoremediation is an environmentally-sound and low-cost method that can treat a variety of contaminants. However, the limitations of these methods include a relatively long duration of treatment due to the growth rate and growing season of the plants. Furthermore, they usually only work effectively in shallow soils or waters and only at relatively low concentrations of the contaminants which are not toxic to the plants. More field studies on phytoremediation are needed to better evaluate its effectiveness in the removal of contaminants from the environment. More research is also needed on the use of different organic and inorganic amendments in order to improve the efficiency of the methods.

# 3.5. Recycling activities

Lindane recycling activities have taken place at different plants (Vijgen 2006; Verber and Varbelo, 2013, Wycisk et al, 2013; IHOBE, 2016, Fernández et al. 2013). Similar situations are also expected to take place at various polluted locations in different countries. Between 4 and 7 million tonnes of waste containing POPs are estimated to have been produced and discarded around the globe during 60 years of lindane production (Vijgen et al. 2011). Therefore, the assessment of contaminated sites and/or building demolitions at a global level should be addressed within the framework of the implementation of the Stockholm Convention since previous experiences in this domain may be applicable for other sites with similar contaminated production plants.

For most of the waste destruction technologies there is the option to convert HCH into HCl or NaCl. Specifically, the recycling of HCH to HCl is a relevant approach to be considered. This applies for a number of the industrial hazardous waste incinerators, BCD, GCPR and Plasma technologies. This possibility should be considered and further investigated. The recycling of HCH (70% chlorine content) could be a sustainable and profitable business for industry, especially since there are considerable quantities of HCH waste on a global scale. About 40 production processes generate HCl as a by-product (technical)<sup>7</sup>

Chemical industry is able to make a part of their capacities in the availability of HCH in the EU. Obviously an economic analysis has to be made. But two companies can be referred as examples of this approach:

- AKZO in the Netherlands has been converting halogenated contaminants to HCl,
- Indaver in Belgium intends to set up a new factory "IndaChlor" in Loon Plage/Dunkirk, to recycle production residues and products containing residual chlorine<sup>8</sup>. The new plant will have a capacity of 40,000 tonnes per year. An additional plant is being constructed in Dunkerque (France).

-

<sup>&</sup>lt;sup>7</sup> https://www.akzonobel.com/ic/products/hydrochloric\_acid/

http://www.dunkerque-port.fr/en/press/news/2016-05-26-setting-up-of-a-factory-from-indaver-to-dunkirk-en-45063.html

# 4. BEST PRACTICES

#### **KEY FINDINGS**

- Multidisciplinary and collaborative approaches result in better management and decision-making tools.
- Sites where lindane waste has been deposited will require continuous long-term monitoring, leachate pump and treatment as well as maintenance activities for decades. DNAPL fraction should also be considered as a specific endpoint to be monitored
- Based on the current experience, HCH-waste stockpiles and landfills can be considered
  as pollution sources for soil, surface and groundwater due to leaching and
  dissemination of the contaminants. Destruction of POPs in contaminated wastes and
  site remediation practices should be considered as best-practices instead of storage
  in landfills.
- The contamination of lindane (classified as a POP) should be considered a problem not only at a European Community level, but also on a global scale. Experiences related to the assessment and remediation of lindane contaminated sites (i.e. building demolition techniques, the restoration of contaminated sites, the development of guidances/tools) may be applicable for other sites with similar contaminated production plants in different countries. This is one main reason why these issues should be addressed with a global approach under the Stockholm Convention on POPs.
- According to the considerations and requirements of the Stockholm Convention regarding the solutions for HCH-waste it is indicated that it should be: "disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low". The HCH-waste locations are usually mega-sites with huge economic costs in terms of their management and restoration. Due to these drawbacks, suitable solutions for HCH-waste has only been found in a few instances and even then they often do not fulfil most of the requirements of the Stockholm Convention. Selecting the cheapest "encapsulation option" would seem to violate the requirements of the Convention.
- Furthermore, problems with many HCH-waste locations have been left unattended over periods of more than 30 or 40 years. Hence, the original extent of the problem and the related costs of cleaning-up additional dumps, have been growing due to leaching and the dissemination of contaminants (see the Aragon case, but also the Slovak case, where now several millions of m³ of groundwater are heavily polluted). The failure to act should be considered as a worst practice since it causes environmental problems and the economic costs of the solution to increase.

# 4.1. Transparency: Construction of the Argalario safety landfill in the Basque Country (Spain)

In 1995 the Government of the Basque Country decided to build in Argalario (Barakaldo) a security landfill to store the HCH waste from over 40 polluted sites. This decision led to a huge public outrage from neighbours, environmentalists and several political parties from the local council (Barakaldo Digital, 2011).

The two lindane-producing facilities were selectively demolished. Residues from this demolition that were contaminated by HCH were stored in a reservoir built for the containment of lands contaminated by HCH (the Argalario safety cell). This was also carried out for the contaminated soils on which both facilities were located. The construction of the safety cell was planned according to best available technologies and submitted to public consult before its construction.

In order to facilitate all the information on the project, both during its construction and maintenance, a "follow-up committee" was created with the participation of representatives from the municipality of Barakaldo, local environmental groups and neighbourhood associations. Also, representatives and technicians from the Basque Country's environment and public health authorities participated in the committee. Regular meetings were held to inform on the construction developments, results from monitoring activities and any other information demanded before each meeting.

An environmental education centre was placed in one of the buildings situated on the landfill. This centre answered demands for information from all kind of organisations, such as research groups, universities, companies, secondary school students, women's associations, environmental groups and public administrations. IHOBE's website also published the data from environmental controls carried-out during the building of the landfill. Demands and doubts raised by the neighbours about the proximity of the landfill to their houses were answered personally. In parallel, all competent departments from the different administrations were kept informed during each stage of the project (Escolar, 2015; IHOBE, 2016; Barakaldo Digital, 2011).

# 4.2. Stakeholder participation and Technical Centre of Coordination (Sabiñánigo)

In order to guarantee the coordination of the different groups participating in the search for solutions to the management of HCH waste and the decontamination of HCH polluted sites in the Sabiñánigo area (see section 2.14), the Government of Aragón decided in 2015 to create three different stakeholder committees:

#### **Institutional Committee**

Its main task is to facilitate the coordination among the different administrations and institutions involved in the management of HCH waste, HCH polluted sites and its consequences. It is made up of representatives from the municipalities in the affected area, the River Ebro Basin Authority, the Irrigation Community of Alto Aragón, the Nature Protection Service of the Guardia Civil (Civil Guard) and the Government of Aragón.

# Social Committee

Its aim is to allow the communication flow and transparency on the management of HCH waste in an orderly way. It is made up of NGOs, business organisations, trade unions and

political parties. For example, after the constitution of the committee all water sampling data was published on the website of Aragón's department of the environment, allowing all stakeholders to have real-time information on the water's chemical quality (Aragón Hoy, 2016a; Aragón Hoy, 2016b; GA, 2016b).

#### **Scientific Committee**

Its main task is to advise the Government of Aragón on the decisions to take on the management of HCH waste and HCH-polluted sites. This Committee should help define the government's decontamination work plan and help develop a forum to address R&D+I needs. It is made-up of an interdisciplinary group of seven scientists of national and international prestige from the fields of hydro-geology, chemistry, soil science, chemical engineering and medicine.

# 4.3. Stakeholder participation: Spanish PNA

This section refers to the elaboration of the Spanish National Implementation Plan (NIP) according to the duties stablished under the Regulation 850/2004 as an example of a multidisciplinary collaborative process (Figure 3).

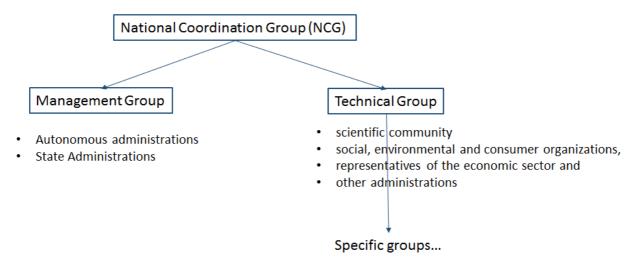
The process for developing this National Implementation Plan (NIP) was launched in January 2005 with the holding of the first general meeting, in which all potentially interested stakeholders were represented in order to establish a specific group that lead this process. The subsequent "National Coordination Group" (NCG) on POPs first met on15 April 2005 when it approved its constitution, the structure and groups that comprise it, rules and the procedural work programme and a schedule of meetings until 2006.

The NCG is made up of a Manager Group (executive unit formed by Autonomous and State Administrations) and a Technical Group (consisting of all stakeholders: the scientific community, social, environmental and consumer organizations, representatives of the economic sector and other administrations). Six specific Working Groups are included in this Technical Group:

- 1. Inventories
- 2. Substitution
- 3. Best Available Techniques / Best Environmental Practices (BAT/BEP)
- 4. Monitoring levels of POPs
- 5. Information and Awareness
- 6. Coordination, Cooperation and Financial Affairs

The NIP is an agreed plan in which around 200 experts of all sectors are involved, whose initiatives or comments have been considered from the beginning and throughout the process.

Figure 3. Schematic representation of the National Coordination Group on POPsination Group on POPs.



This Technical Group on COPs is still in action, for example, it worked on the updating of the Spanish NIP in 2013. April 2016 was the last time that the Technical Group met. The agenda included a topic that appeared in our first NIP: lindane contamination. Three perspectives of lindane contamination were presented during that meeting: from the Autonomous Community of Aragon, from a Public Company (EMGRISA) which is developing one of the projects in the affected area, and from an environmental NGOs (Ecologistas en Acción).

# 4.4. Factory decontamination: Hamburg Moorfleet site.

Verber and Varbelow (2013) described the dismantling and demolition technologies, site securing and environmental assessment of a lindane production plant in Hamburg. Due to the low production efficiency, in most of the production plants HCH waste was recycled producing residues with high polychlorinated dibenzo-p-dioxin and dibenzofuran (PCDD/PCDF) levels, among other organochlorinated compounds.

The main approach consisted of a) exploration, b) remediation and c) containment phases. These activities started in 1984 and were concluded in 1989, and a 10-year evaluation phase was agreed.

# A. Exploration

- a.1. Environmental monitoring data:
  - o PCDD/PCDF and extractable organohalogen compounds, ground water and soil samples were analysed. Standardized protocols were used;
  - o 196 drillings were performed on and around the production site;
  - o 21,000 single analysis measurements for the main pollutant parameters from samples from different deeps;
  - o A total amount of organochlorine inventory was estimated for soil and groundwater, including DNAPL, below the production site; and
  - o DNAPL flow gradient of the contamination plume was also modelled.
- a.2. On site monitoring of pollutants for workers were also carried out.

#### B. Remediation

#### b.1. Environmental remediation

- o Thorough clean-up of the highly contaminated soil by excavation and onsite incineration of 25,000 m³ of highly polluted soil and 10,000 m³ of the most contaminated building parts. However, the onsite incineration approach failed due to corrosion problems and other technical difficulties and was stopped after several months.
- o Groundwater was pumped, cleaned over activated carbon, and pumped back to the ground water that had been enhanced with oxygen and nutrients to increase the biodegradation of contaminants by microorganisms already present in the groundwater.
- The *in-situ* bioremediation, which had shown good degradation performance in laboratory (Zetter, 1996), did not show the expected results in the field and was thus discontinued.

In this first remediation phase, approximately 75 million euro was spent without significant remediation effects.

# b.2. Remediation of the buildings

- o Contaminants to be remediated included PCDD/PCDF that were unintentionally generated during 2,4,5-T synthesis from HCH recycling activities.
- Special demolition techniques were developed to avoid the release of dust and pollutants reducing risks and personnel exposure. A grade demolition strategy was applied:
  - o Highly contaminated buildings were demolished under full protection housing, break down operations were performed under a fine water spray film. Sprayed water was sampled and cleaned over activated carbon.
  - o Buildings with only surface contamination were demolished after removal of the contaminated materials (i.e. plaster, bricks, paints...)
  - o Buildings without specific contaminations were de-dusted with industrial vacuum cleaners.
- o A data sheet was established for each building to record a complete documentation of contaminants.

# C. Containment

#### c.1. Securing strategy of the site (Figure 4):

- o Construction of a cut-off wall covering the entire production area down to a depth of approximately 46 m, reaching 2 m into the water and solvent/DNAPL clay layer.
- o Remediation of the contamination plume outside the area: a pump-and-treat concept was developed to establish a pressure gradient for water flow towards the site.
- o Groundwater from the contaminated plume that had migrated outside the containment area was pumped to reduce groundwater contamination,
- o Asphalt concrete covering of the entire area after removal of the buildings.

Public road
Former factory area

Moorfleeter Canal

7

225 m

Moorfleeter Canal

Figure 4. Underground scheme of the securing measures

**Source:** Weber and Varbelow, 2013; 1 Cut-off walls, 2 bulkhead, 3 highly polluted soil layer, 4 asphalt surface cover, 5 DNAPL, 6 DNAPL well, 7 well for lowering ground water table, 8 well for groundwater purification outside of the containment, 9 groundwater treatment

The total cost of remediation and containment activities no the production site alone was around 110 million euro. The cost for pump-and-treatment of the site was approximately. 1 million euro/year.

# **Current situation (2013)**

-50 Meter

The securing wall is still fully operational. The contamination in the plume outside the area has decreased as a result of pumping wells outside the construction area. From the estimated 830 tonnes of chlorinated organics underground, 10-30 tonnes have been pumped and destroyed.

The pump-and-treatment and monitoring activities are ongoing and will have to be continued in future. No specific time limit is set.

# 4.5. Underground water monitoring: Bitterfeld-Wolfen

Wycisk et al. (2013) reflects an integrated methodology for assessing the current situation of the large-scale groundwater contamination of the Bitterfeld/Wolfen mega-site. The regional groundwater contamination of Bitterfeld/Wolfen has been influenced by several environmental impacts including various chemical production processes, multiple resulting waste dumps and extensive open-pit lignite mining for more than a century. The hydrochemical situation is characterised by a complex mixture of organic compounds (chlorinated aliphatic and aromatic hydrocarbons), which comprises a high diversity of individual organic substances as well as a high regional variability of these contaminants. Regional distribution patterns explain the differences between the levels of HCH occurrence in the two local aquifer systems.

The approach for assessing the situation involves an integrarated methodology including: a) multiple field sampling campaigns, b) geo-statistical techniques for the regionalisation of analytical data to create a conceptual model of contaminant distribution patterns in regional surfaces waters and groundwater, c) the verification of the model conception of contaminant distributions by 3-D aquifer geometries modelling.

#### A. Field sampling campaigns

Since the industrial dumpsites are not completely sealed, the groundwater was/is significantly affected by the chemical inventory of chlorinated aliphatic and aromatic hydrocarbons of the deposits and former releases from production processes. The regional long-term groundwater monitoring considers approximately 180 individual organic substances with about 60 priority contaminants.

Data analyses have been performed on regional groundwater monitoring data from about 10 years, containing approximately 3,500 samples and up to 180 individual organic parameters from almost 250 observation wells. Run-off measurements as well as water samples were taken biweekly from local creeks during a period of 18 months. Data from long-term monitoring provide much more information about the contamination characteristics than a single survey and suppress the over- or underestimation of the polluted system.

In order to characterise the spatial dimension of the regional groundwater pollution as well as to suggest selected substances which should be investigated in more detail, organic compounds were ranked according to their risk potential. Also, the potential remobilization of river sediments from a surrounding area 60 km2 was taken into account.

#### B. Conceptual model for the regionalisation of analytical data'

The long-term HCH contaminant discharge originated from the disposal(s) of contaminated soils into the upper (Quaternary) and lower (Tertiary) aquifer and was spread due to the regional dominating groundwater flow dynamics.

Thus, long-term contaminant release from deposits and local production areas was influenced by various mining-related changes of the hydraulic system and formed the presently observed contaminant distribution patterns with all their complexity. Multiple HCH sources lead to highly complex distribution patterns at a regional scale that are not comparable to single-source plume geometries. Therefore, a clear source localisation is complicated and comprises various probable input scenarios.

A GIS-based classification of the alpha-HCH regionalisation enables a quantitative estimation of the overall affected area of the region. Here, analysed for the Quaternary aquifer, a total area of about 38 km<sup>2</sup> is affected.

The software system GSI3D© (former Geo-Object) has been used to generate a 45-km²-wide, geological high-resolution 3-D model of the entire industrial region Bitterfeld/Wolfen and the surrounding downstream area. This geometric model has been incorporated subsequently into a numerical groundwater model. Using the finite element model FEFLOW© for simulating groundwater flow and solute transport processes, the entire model domain of the regional flow/transport model amounts to 330 km² and is structured into 13 individual hydrogeological subformations.

#### C. 3-D aquifer geometries modeling

These data, preprocessed and stored in a GIS system, were implemented in the 3-D numerical model to represent the regional flow and solute transport dynamics before and after the flood event in August 2002. The successful model calibration process ensured a representative simulation of local piezometer dynamics.

A numerical finite element model has been established which involves the following objectives:

- 1. A transient path-line generation to identify potential contaminant pathways that originated from the production areas and the identification of affected observation wells or surface water bodies after the end of active lignite mining; and
- 2. Predictive calculations of the hydraulic situation, that has since changed, during and after the flooding event of the Goitzsche Lake in August 2002.

Thus, a full integration process of geological field data, high-resolution 3-D geology, flow and transport modelling and future fate contaminant scenarios has been done successfully.

Vijgen (2006) and Vijgen et al. (2010) state with respect to the numerous existing HCH waste disposals worldwide that a successful implementation of the Stockholm Convention requires a detailed site investigation of the HCH/POPs waste deposits and their pollutant releases for an adequate management of related impacts on human health and ecosystem integrity.

#### 4.6. HCH Polluted sites identification: Twente, Netherlands

HCH was produced tin the city of Twente, Netherlands between 1948 and 1952. In the seventies, the authorities discovered, for the first time, HCH disposal sites outside the companies' premises, as far as 20 km away from the factory. With the entry into force of the Interim Act on Soil Clean-up in 1983 the systematic identification of HCH polluted soils was undertaken.

The following routes were used to identify HCH polluted sites:

- An appeal was made in the local press, asking for people who had knowledge of transport and disposal of waste or soil from the company in the area.
- Drivers of transport companies who had dealt with the HCH manufacturer, AKZO, reacted to the appeal and were interviewed.
- The archives of the owners of the companies' land were investigated, as well as the archives on environmental licences.
- Air photography was carried out, first to try to spot the contaminated site, and, secondly, to look for sites with deviations in the soil profile, such as filled-up sand or clay winnings, digging activities, etc.
- A rough field check and chemical analyses of two mixed samples per hectare.
- Quality control of cow's milk as many sites were used as pasture.

In total, 132 sites were suspected of being polluted with HCH. After a rough field check and chemical analysis, 62 sites proved to be clean. After further investigations, another 28 sites also proved to be clean. Finally, 42 polluted sites were identified (Grinwis and de Jong, 1992).

#### 5. INFORMATION ON LINDANE

#### **KEY FINDINGS**

- Most countries provide information regarding hazardous chemicals and POPs, but this information does not always include information on lindane.
- Those regions with lindane mega-polluted-sites, usually thousands of tonnes of soils and water pollution, use to publish websites with information regarding the situation and remediation approaches accomplished. This kind of information use to be pushed by citizens' pressure.

This section is intended to assess the transparency and level of information provided to citizens. The information in this section has been summarized from the responses provided in questionaries. All questionnaires received indicated the existence of an official website providing information on hazardous chemicals, but the information on lindane concern was not so clear. Information on lindane was identified especially in locations in which HCH-contamination sites have been identified, resulting in high concern from the population.

Table 19. Information to citizens from different authorities and organizations

Issues		Member States							organizations	
Issues	CZ	DE	DK*	ES*	HU	LV	RO	NL*	GP	ВС
Health and/or environmental risks	Yes	Yes	Yes	Yes	Yes	-	Yes	Yes	Yes	-
Polluted sites	Yes	Yes	Yes	Yes	-	Yes	-	Yes	Yes	Yes
Exposure through articles and/or food and/or other sources	Yes	Yes	Yes	Yes	-	-	-	Yes	Yes	-
Environmental and human monitoring data	Yes	Yes	Yes	-	-	Yes	-	Yes	Yes	Yes
Recommendations to reduce exposure	Yes	Yes	Yes	-	Yes	-	Yes	Yes	Yes	Yes
Regulations and policies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Links to other websites	Yes	Yes	Yes	Yes	-	Yes	-	Yes	Yes	Yes

Not specifically on lindane;

Table 20. Websites with information on chemicals

. 45.0 20. 10	Websites from Member States and organizations
Czech Republic	http://www.recetox.muni.cz/nc/index-en.php http://www.genasis.cz/index-en.php http://www.irz.cz http://arnika.org/lindan-gama-hch (NNO)
Germany	Information on HCH contamination is in principle available on many different websites. No specific website is available summarising all information on HCH.
Denmark	Information on hazardous chemicals can be found on different websites. No specific website is available regarding lindane
Spain	Information on hazardous chemicals can be found on different websites. No specific website is available regarding lindane <a href="http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/temas/productos-quimicos/">http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/temas/productos-quimicos/contaminantes-organicos-persistentes-cop/</a>
Hungary	http://okbi.hu/page.php?trid=6; http://www.greenpeace.org/hungary/hu/ http://reflexegyesulet.hu/index.php/nulla-hulladek http://www.ecotox.hu/ecotox2/index.php
Latvia	Information is located at "Latvian Environment, Geology and Meteorology Centre" website: <a href="http://www.lvgmc.lv/lapas/vide/vide?id=1134&amp;nid=320">http://www.lvgmc.lv/lapas/vide/vide?id=1134&amp;nid=320</a>
Romania	Website of Ministry of Environment, Water and Forests: <a href="http://www.mmediu.ro/categorie/pop-s/58">http://www.mmediu.ro/categorie/pop-s/58</a> Website of National Environment Protection Agency: <a href="http://www.anpm.ro/poluanti-organici-persistenti-pops-">http://www.anpm.ro/poluanti-organici-persistenti-pops-</a>
The Netherlan ds	- Not specifically to lindane, but to hazardous chemicals, yes: http://www.rivm.nl/en/ https://www.government.nl/topics/hazardous-substances https://www.government.nl/ministries/ministry-of-infrastructure-and-theenvironment
Greenpea ce	Greenpeace often informs the public: <a href="www.greenpeace.hu">www.greenpeace.hu</a> , greenpeace.blog.hu also a blog vegyi.blog.hu & some Facebook groups
Switzerla nd	www.bafu.admin.ch

	Websites from Member Chates and appearing tions
	Websites from Member States and organizations
Basque Country Governm ent	Information on lindane is provided: Plan of contaminated soils of the Basque Country 2007-2012 (in Spanish) http://www.ingurumena.ejgv.euskadi.eus/r49- orokorra/es/contenidos/plan/suelos contaminados/es plan/adjuntos/plan sue los contaminados.pdf  Information on the construction of safety cells (in Sapnish): http://www.ihobe.eus/Publicaciones/Ficha.aspx?IdMenu=750e07f4-11a4- 40da-840c-0590b91bc032&Cod=ef1f5a8a-683d-4a18-84c5- 84aa9cf5fe3d&Idioma=es-ES&IdGrupo=PUB&IdAno=2002&IdTitulo=001  Information on the evolution of HCH concentrations in the Oiola reservoir damp (in Spanish): http://www.uragentzia.euskadi.eus/informe_estudio/evolucion-de-las- concentraciones-de-hexaclorociclohexano-en-el-embalse-oiola-valle-de- trapaga-trapagaran/u81-0003771/es/  Information on the evolution of the chemical status in the river Zadorra (monitoring network of the Basque Country): http://www.uragentzia.euskadi.eus/informacion/ultimos-informes/u81- 0003342/es/  Hydrological Plan of the Eastern Bay of Biscay: http://www.uragentzia.euskadi.eus/informacion/plan-hidrologico-de-la- demarcacion-hidrografica-del-cantabrico-oriental-2015-2021/u81-
Governm ent of Aragón	0003333/es/ All information related to lindane contamination is published on the website <a href="http://www.aragon.es/lindano">http://www.aragon.es/lindano</a> .
Forter, M	Independent scientist for municipalities, residents and environmental organisations. Switzerland (and France) <a href="http://www.martinforter.ch">http://www.martinforter.ch</a>
Internatio nal HCH & Pesticides Associatio n IHPA)	In the library of IHPA at <a href="http://www.ihpa.info/resources/library">http://www.ihpa.info/resources/library</a> since 1993 all information on publications on Lindane and HCH-related issues can be found in the 11 published HCH and Pesticides Forum books of 12 Fora (the 1st and 2nd Forum have been compiled as one book), that can be downloaded free of charge  Further are various versions of Technology Fact Sheets for POPs destruction available in the library

#### 6. REFERENCES

Abhilash, P.C., Srivastava, S., Srivastava, P., Singh, B., Jafri, A. and Singh, N. (2011).
 Influence of rhizospheric microbial inoculation and tolerant plant species on the rhizoremediation of lindane. Environmental and Experimental Botany, 74:127–130.

- Abhilash, P.C., Singh, B., Srivastava, P., Schaeffer, A. and Singh, N. (2013).
   Remediation of lindane by Jatropha curcas L: Utilization of multipurpose species for rhizoremediation. Biomass and Bioenergy, 51: 189-193.
- Agassi, E., Krijger, P., Vis, P. (1998). Thermal desorption, a definite solution for the eliminaiton of HCH. Proceedings from the 5th International HCH and pesticides Forum, Bilbao, Spain, June 1998, IHOBE, pp. 145-151.
- AI (Ayuntamiento de Iguzquiza), (2016). Residuos de lindano. [Lindane waste]. <a href="http://www.ayuntamientodeiguzquiza.es/index.php/actualidad/noticias/item/235-residuos-de-lindano">http://www.ayuntamientodeiguzquiza.es/index.php/actualidad/noticias/item/235-residuos-de-lindano</a>. Accessed 15 October 2016.
- Aken, B.V., Correa, P.A., Schnoor, J.L. (2010). Phytoremediation of polychlorinated biphenyls: new trends and promises. Environ Sci Technol 2010;44:2767-2776.
- AMAP (2002). Artic Pollution- Human Health. Arctic Monitoring and Assessment Programme, Oslo 2002. <a href="http://www.amap.no/documents/doc/arctic-pollution-2002/69">http://www.amap.no/documents/doc/arctic-pollution-2002/69</a>
- Amarante, D. (2000). Applying In Situ Chemical Oxidation, several oxidizers provide an effective first step in groundwater and soil remediation. Pollution Engineering. Cahners Business Information. Pollution Engineering, 32 (2): 40-42.
- Anitescu, G. and Tavlarides, L.L. (2005). Oxidation of biphenyl in supercritical water: reaction kinetics, key pathways, and main products. Industrial & Engineering Chemistry Research, 44: 1226–1232.
- Anupama, K.S. and Paul, S. (2009). Ex situ and in situ biodegradation of lindane by Azotobacter chroococcum, Journal of Environmental Science and Health, Part B, 45 (1): 58-66.
- Aragon Hoy (2016a). Los comités institucional y social conocen de primera mano los avances del Ejecutivo para la descontaminación de lindano. <a href="http://aragonhoy.aragon.es/index.php/mod.noticias/mem.detalle/area.1341/id.184">http://aragonhoy.aragon.es/index.php/mod.noticias/mem.detalle/area.1341/id.184</a>
   116
- Aragon Hoy (2016b). El Comité Científico para la descontaminación de lindano elogia la mejora de los sistemas de control para la detención de HCH en la cuenca del Gállego. <a href="http://aragonhoy.aragon.es/index.php/mod.noticias/mem.detalle/relmenu.47/id.18">http://aragonhoy.aragon.es/index.php/mod.noticias/mem.detalle/relmenu.47/id.18</a> 3968
- Araújo, M. M., Ignatius, S. G., Oliveira, A. O., Oliveira, S. S., Fertonani, F. L. and Paste, I. A. (2016). Thermal desorption of HCH Temperature and time effects, Journal of Thermal Analysis and Calorimetry, 123 (2): 1019–1029.
- ASDEN (personal communication). Monitoring of the groundwater quality in the surroundings of the Mine Gandalia, (Borobia, Soria). (Seguimiento de la calidad de las aguas subterráneas en el entorno de la mina de Gandalia en T.M. de Borobia (Soria)). Report and answer by the Confederación Hidrgráfica del Ebro- MAGRAMA to ASDEN.
- ASDEN, (2015). Encontrado Lindano en una mina de Borobia. [Lindane found in a mine in Borobia]. <a href="http://www.ecologistasenaccion.org/article30108.html">http://www.ecologistasenaccion.org/article30108.html</a>

 Atlántico (17 February 2012). El lindano en Torneiros supera en cinco veces lo autorizado. [Lindane in Torneiros excedes five time authorised concentrations]. <a href="http://www.atlantico.net/articulo/area-metropolitana/lindano-torneiros-supera-veces-autorizado/20120218084843166871.html">http://www.atlantico.net/articulo/area-metropolitana/lindano-torneiros-supera-veces-autorizado/20120218084843166871.html</a>

- ATSDR (2005). Toxicological profile for hexachlorocyclohexanes. U. S. Department of Health & Human Services. Public Health Service. Agency for Toxic Substances and Disease Registry. August, 2005. http://www.atsdr.cdc.gov/toxprofiles/tp43.html
- Aufwändige Grundwassersanierung geplant (2016) Lugwigshafen am Rhein Website: <a href="http://www.ludwigshafen.de/presse/detail/news/2016/06/21/aufwaendige-grundwassersanierung-geplant/">http://www.ludwigshafen.de/presse/detail/news/2016/06/21/aufwaendige-grundwassersanierung-geplant/</a>. Accessed 15 October 2016.
- AV (Ayuntamiento de Viana), 1990. Letter from the municipality of Viana to the Environment authorities of Navarra informing about the dumping of HCH waste by INQUINOSA.
- Babel, S. and Kurniawan, T.A. (2003). Low-cost adsorbents for heavy metals uptake from contaminated water: a review. J. Hazard Mater., 28; 97(1-3): 219-43.
- Barakaldo Digital (3.1.2011). Ihobe destina 300.000 euros a vigilar el depósito de residuos contaminantes y lindane de Argalario. [Ihobe allocates 300.000 euros for surveillance of the waste and lindane lendfill of Aragalario]. http://barakaldodigital.blogspot.com.es/2011/01/ihobe-destina-300000-eurosvigilar-el.html. Accessed 4 November 2016.
- Becerra-Castro, C., Prieto-Fernández, A., Kidd, P. S., Weyens, N., Rodríguez-Garrido, B. Touceda-González, M., Acea, M. J. and Vangronsveld, J. (2013). Improving performance of Cytisus striatus on substrates contaminated with hexachlorocyclohexane (HCH) isomers using bacterial inoculants: developing a phytoremediation strategy. Plant Soil 362:247–260.
- Benimeli, C.S., González, A.J., Chaile, A.P., Amoroso, M.J. (2007) Temperature and pH effect on lindane removal by Streptomyces sp. M7 in soil extract. J. Basic Microbiol., 47, 468–473.
- Benimeli, C.S., Fuentes, M.S., Abate, C.M., Amoroso, M.J. (2008). Bioremediation of lindane-contaminated soil by Streptomyces sp. M7 and its effects on Zea mays growth. International Biodeterioration & Biodegradation 61: 233–239.
- Beránek, M. and Havel, M. (2006). Lindane in the Czech Republic. International POPs Elimination Project IPEP. Czech Republic, April 2006.
- Betenzos (personal communication). Answers to the questionnaire. See Annex II of this document.
- Böltner, D., Godoy, P., Muñoz-Rojas, J., Duque, E., Moreno-Morillas, S., Sánchez, L. and Luis Ramos, J. (2008). Rhizoremediation of lindane by root-colonizing Sphingomonas. Microbial Biotechnology 1(1): 87–93.
- Börner, H. (2012). Pesticides in Ground and Surface Water. Springer Science & Business Media Landesanstalt für Umweltschutz Baden-Württemberg (1993) Stoffbericht HCH. Landesanstalt für Umweltschutz Baden-Württemberg, Karlsruhe.
- Bouwknegt (personal communication). Answers to the questionnaire. See Annex II of this document.
- Buser H. and Muller, M.D. (1995). Isomer and enantioselective degradation of hexachlorocyclohexane isomers in sewage sludge under anaerobic conditions. Environ. Sci. Technol. 29, 664–672.

- CAN, (2009). Lindane Risk Assessment. Health Canada Pest Management Regulatory Agency, REV2009-08. <a href="http://publications.gc.ca/site/eng/355281/publication.html">http://publications.gc.ca/site/eng/355281/publication.html</a>
- Carlon, C. (Ed.) (2007). Derivation methods of soil screening values in Europe. A review and evaluation of national procedures towards harmonization. European Commission, Joint Research Centre, Ispra, EUR 22805-EN, 306 pp.
- CHE (Confederación Hidrográfica del Ebro) (2010). Environmental analysis and risk assessment of the sediments and the surroundings of the dam of Sabiñánigo (Huesca)Análisis ambiental de los sedimentos y del entorno del embalse de Sabiñánigo (Huesca) y evaluación de riesgos. DOCUMENTO No 2. Caracterización medioambiental.
   http://195.55.247.234/webcalidad/estudios/otrosestudios/2010 analisis embalse segonal.
  - http://195.55.247.234/webcalidad/estudios/otrosestudios/2010 analisis embalse s abi/02 caracterizacion ambiental.pdf
- Cheremisinoff, P.N. and Ellerbush, F. (1979). Carbon adsorbtion hand book. Michigan: Ann Arbor Science Publishers.
- Cherian, S. and Oliveira, M. (2005). Transgenic plants in phytoremediation: recent advances and new possibilities. Environ Sci Technol, 39:9377-90.
- Cobouw (1994). Alders geeft startsein bodemsanering Handelskade.
- http://www.cobouw.nl/artikel/116556-alders-geeft-startsein-bodemsaneringhandelskade
- CPEO, (2010). Clean Technology descriptions. Centre for Public Environmental Oversight. <a href="http://www.cpeo.org/techtree/ttdescript/plarctech.htm">http://www.cpeo.org/techtree/ttdescript/plarctech.htm</a>
- Crespo, N., (2001). HCH-polluted soils in highly populated areas in "O Porriño" (Galicia, Northwest Spain). 6th International HCH and Pesticides Forum Book. http://www.hchforum.com/6th/forum\_book/index.htm
- Cuyten, J. 1999. Soil Treatment technologies II: Physical and Chemical menthods. Cleanining of soil contaminated with HCH, from laboratory test to commercial practical application. Proceedings from the 5th International HCH and pesticides Forum, Bilbao, Spain, June 1998, IHOBE.
- Dashtban, M., Schraft, H., Syed, T.A. and Qin, W. (2010). Fungal biodegradation and enzymatic modification of lignin. Int J Biochem Mol Biol., 1(1): 36–50.
- del Moral, J.A. (2012). ¿Qué fue del lindane?[What happened with the lindane?]
   Munipality of Barakaldo Webpage. <a href="http://www.ezagutubarakaldo.net/es/que-fue-del-lindane/">http://www.ezagutubarakaldo.net/es/que-fue-del-lindane/</a> Accessed 1 November 2016).
- Dubey, R.K., Tripathi, V., Singh, N., Abhilash, P.C. (2014). Phytoextraction and dissipation of lindane by *Spinacia oleracea* L. Ecotoxicol Environ Saf. 109:22-6.
- <u>EC</u> (European Commission) (2005). Environmental quality standards (EQS). Siubstance datasheet: Hexachlorocyclohexanes (incl lindane). CAS no: 608-73-1; EC no: 58-89-9.. <a href="https://circabc.europa.eu/sd/a/e7304cd5-1a9b-49a9-9a22-54bcc8e5510a/18">https://circabc.europa.eu/sd/a/e7304cd5-1a9b-49a9-9a22-54bcc8e5510a/18</a> HCHs-combined EQSdatasheet 310705.pdf
- EC (European Commission) (2016). Soil. European Commission (Environment). http://ec.europa.eu/environment/soil/index en.htm
- Ehemaliges Metrogelände Saniert (2014). Ludwigshafen am Rhein Website: <a href="http://www.ludwigshafen.de/presse/detail/news/2014/12/12/ehemaliges-metrogelaende-saniert/">http://www.ludwigshafen.de/presse/detail/news/2014/12/12/ehemaliges-metrogelaende-saniert/</a> Accessed 1 November 2016.

- El-Kady, A.A., Carleer, R., Yperman, J. and Farah, J.Y. (2013). Optimum Conditions for Adsorption of Lindane by Activated Carbon Derived from Date Stones. World Applied Sciences Journal, 27 (2): 269-279.
- Elliott, D., Lien, H., and Zhang, W. (2009). "Degradation of Lindane by Zero-Valent Iron Nanoparticles." J. Environ. Eng., 135(5): 317-324.
- El País (14 October 2001). La planta de Barakaldo terminará de eliminar el lindane en un mes. http://elpais.com/diario/2001/10/15/paisvasco/1003174813 850215.html
- Escolar, L. (2015). HCH: a problem solved in the Basque Country. Presentation at the 13th
   HCH and Pesticides Forum..
   <a href="http://www.hchforum.com/presentations/pdf/Block01">http://www.hchforum.com/presentations/pdf/Block01</a> Spanish%20Experiences/1.1
   HCH Basque Country.pdf
- Fahlberg- List (2016). Wikipedia <a href="https://de.wikipedia.org/wiki/Fahlberg-List#Lindan.">https://de.wikipedia.org/wiki/Fahlberg-List#Lindan.</a> Accessed 2 November 2016.
- Fernández, J., Arjol, M.A. and Cancho, C. (2013). POP-contaminated sites from HCH production in Sabiñánigo, Spain. Environ Sci Pollut Res Int, 20 (4):1937-1950.
- Ficko, S.A., Rutter, A., Zeeb, B.A. (2010). Potential for phytoextraction of PCBs from contaminated soils using weeds. Sci Total Environ, 408:3469-76.
- Faro de Vigo, El. (10 November 2010). La Xunta concluye el proceso de realojo de los afectados por el parque de lindano. <a href="http://www.farodevigo.es/comarcas/2010/11/10/xunta-concluye-proceso-realojo-afectados-parque-lindano/489469.html">http://www.farodevigo.es/comarcas/2010/11/10/xunta-concluye-proceso-realojo-afectados-parque-lindano/489469.html</a>.
- Foo, K.Y. and Hameed, B.H. (2009). Recent developments in the preparation and regeneration of activated carbons by microwaves, Adv. Colloid Interface Sci., 149: 19-27.
- Forter, M (2015). The production of Lindane by Ugine Kuhlmann Huningue (France) and the consequences for the city of Basel (Switzerland). Presentation at the 13th HCH & Pesticides Forum, Zaragoza, Spain.,
- http://www.martinforter.ch/images/news/2013 09 25/Forter-Lindane by UgineKuhlmannn.pdf.
- Fuentes, M.S.; Benimeli, C.S.; Cuozzo, S.A.; Amoroso, M.J. (2010). Isolation of pesticide-degrading actinomycetes from a contaminated site: Bacterial growth, removal and dechlorination of organochlorine pesticides. Int. Biodeterior. Biodegrad., 64: 434–441
- Fuscoletti, V., Achene, L., Gismondi, F., Lamarra, D., Lucentini, L., Spina, S., Veschetti, E. and Turrio-Baldassarri, L. (2015). Presence of Epsilon HCH Together with Four Other HCH Isomers in Drinking Water, Groundwater and Soil in a Former Lindane Production Site. Bulletin of Environmental Contamination and Toxicology, 95 (1): 108–115.
- GA (Gobierno de Aragón) (2016a). Website of the project DISCOVERED LIFE. <a href="http://www.lifediscovered.es/">http://www.lifediscovered.es/</a> Accessed 2 November 2016.
- GA (Gobierno de Aragón) (2016b). Jornada de trabajo en Sabiñánigo de la comisión científica de apoyo a las actuaciones de descontaminación de los espacios afectados por la contaminación derivada de la actiidad de la empresa INQUINOSA. 3 febrero de 2016.

https://www.aragon.es/estaticos/GobiernoAragon/Departamentos/AgriculturaGanaderiaMedioAmbiente/TEMAS MEDIO AMBIENTE/AREAS/LINDANO/COMITES HCH/ACTA COMITE CIENTIFICO 20160203.pdf

- GA (Gobierno de Aragón) (2016c). Comités HCH- [HCH Committees]. <a href="http://www.aragon.es/DepartamentosOrganismosPublicos/Departamentos/DesarrolloRuralSostenibilidad/AreasTematicas/Lindano/ci.COMITES HCH.detalleDepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/DepartamentosOrganismosPublicos/Departamentos/DesarrolloRuralSostenibilidad/AreasTematicas/Lindano/ci.COMITES HCH.detalleDepartamentosOrganismosPublicos/DepartamentosOrganismosP
- García, A. (personal comunication). Answers to the questionnaire. See Annex II of this document.
- Götz, R., Sollolek, V. and Weber, R. (2013). The dioxin/POPs legacy of pesticide production in Hamburg: Part 2—waste deposits and remediation of Georgswerder landfill. Environ Sci Pollut Res 20:1925-1936.
- Gravesen (personal communication). Answers to the questionnaire. See Annex II of this document.
- Grinwis, A. (1992). "Deventer Handelsakade" Project. Technical interpretation of the choice of a hydrogeological isolation option with supplementary measures to facilitate building development. International HCH and Halogentated pesticides Forum. Compilation of 1<sup>st</sup> and 2<sup>nd</sup> HCH Forum Book.
- Grinwis, A. and de Jong, G. (1992). Ten years of soil clean up in the HCH-Project in Twente, The Netherlands. International HCH and Halogentated pesticides Forum. Compilation of 1<sup>st</sup> and 2<sup>nd</sup> HCH Forum Book.
- Gupta, V.K., Jain, C.K., Ali, I., Chandra, S., Agarwal, S. (2002). Removal of lindane and malathion from wastewater using bagasse fly ash—a sugar industry waste. Water Res, 36: 2483-2490.
- Hassan, A.M., El-Moteleb, M.A. and Ismael, A.M. (2009). Removal of lindane and malathion from wastewater by activated carbon prepared from apricot stone. Ass. Univ. Bull. Environ. Res. 12 (2): 1-8.
- Hauzenberger, I., Perthen-Palmisalo, B. and Herrmann, R. (2004). Reports on substances scheduled for re- assessments under the UNECE POPs Protocol, Technical Review Report on Lindane, Austria.
  - https://www.unece.org/fileadmin/DAM/env/lrtap/TaskForce/popsxg/2000-2003/lindane.pdf
- Heinisch, E., Jonas, K. and Klein, S. (1993) HCH isomers in soil and vegetation from the surroundings of an industrial landfill of the former GDR, 1971-1989. The Science of the Total Environment, Supplement 1993: 151-159.
- Heinisch, E. Kettrup, A., Bergheim, W. and Wenzel, S. (2005). Persistent Chlorinated Hydrocarbons (PCHC), source oriented monitoring in aquatic media 3. The isomers of Hexachlorocyclohexane. Fresenius Environmental Bulletin, 14 (6): 444-462.
- Hennebel, T., Simoen, H., Verhagen, P., De Windt, W., Dick, J., Weise, C. Pietschner, F., Boon, N. and Verstraete W. 2011. Biocatalytic dechlorination of hexachlorocyclohexane
- by immobilized bio-Pd in a pilot scale fluidized bed reactor. Environ Chem Lett 9:417–422.

 Hirth, T., Heck, L., Jahnke, S. et al., (1998). Supercritical water oxidation-waste destruction and synthesis. In: Koatsuryoku no Kagaku to Gijutsu 7 (Proceedings of International Conference-AIRAPT-16 and HPCJ-38-on High Pressure Science and

Technology, 1997). 1375.

 Holoubek, E., Klánová, J, Vijgen, J. (2009). Global, regional and local fate of HCHs and other pesticides – problems, risks, challenges. 10<sup>th</sup> International Forum on HCH and Pesticides, Brno, Czech Republic, 2009.

- Holoubek, I , Klánová J, Cupr, P, Sánka, M (2011) δ-Hexaxhlorocyclohexane Potential marker of unknown environmental processes?. Proceedings from the 11<sup>th</sup> International HCH and Pesticides Forum, Gabala, Azerbaijan, September 2011, IHPA and UNEP, pp. 108-112.
- HSBD, (2006). Hazardous Substances Data Bank. Bethesda (MD): National Library of Medicine (US); 2006 (Last Revision Date 20 Dec 2006; cited 26 Sep 2016). Lindane; Hazardous Substances Databank Number: 646. http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB. Accessed 15 October 2016.
- IARC, (2016). Carcinogenicity of lindane, DDT, and 2,4-dichlorophenoxyacetic acid. Volume 113 of the IARC Monographs. http://monographs.iarc.fr/ENG/Monographs/vol113/index.php
- ICIS News, (17 February 2004). Dutch envt ministry pursues HCH-pollution case against Akzo. http://www.icis.com/resources/news/2004/02/17/558741/dutch-envt-ministry-pursues-hch-pollution-case-against-akzo/
- IETU NEWS (2012). FOKS (Focus On Key Sources of Environmental Risks). <a href="http://projectfoks.zuova.cz/wp-content/uploads/2009/07/foks newsletter vol6.pdf">http://projectfoks.zuova.cz/wp-content/uploads/2009/07/foks newsletter vol6.pdf</a>; <a href="http://www.ietu.katowice.pl/eng/News/ns/ietu">http://www.ietu.katowice.pl/eng/News/ns/ietu</a> news 8 2012 www.pdf
- IHOBE. Aspectos innovadores [Innovative aspects]. http://www.ihobe.eus/Paginas/Ficha.aspx?IdMenu=af182443-7f60-4c7e-a87f-7566f410bacf&Idioma=es-ES. Accessed 4 November 2016.
- IHPA, (2009a). Provisional POPs Technology Specification and Data Sheets for the Secretariat of the Basel Convention. <a href="http://www.ihpa.info/docs/library/reports/Pops/June2009/SBC LogoGCPRDEF 190109">http://www.ihpa.info/docs/library/reports/Pops/June2009/SBC LogoGCPRDEF 190109</a> .pdf
- IHPA, (2009b). New POPs technology, specification and data sheets. Gas-Phase Chemical Reduction (GPCR). http://www.ihpa.info/docs/library/reports/nato/NATO\_EcologFactSh&Annex3.pdf
- IHPA, (2009c). New POPs technology, specification and data sheets. Super Critical Water Oxidation (SCWO).
  <a href="http://www.ihpa.info/docs/library/reports/Pops/June2009/SBC\_Logo\_SCWO\_Prov(1\_090109)MTKUsedBurningIssue08June09.pdf">http://www.ihpa.info/docs/library/reports/Pops/June2009/SBC\_Logo\_SCWO\_Prov(1\_090109)MTKUsedBurningIssue08June09.pdf</a>
- IHPA, (2009d). New POPs technology, specification and data sheets. Plasma Arc. http://www.ihpa.info/docs/library/reports/Pops/June2009/SBCPLASCONSBCLogoDE FCLEANVERSION 190109 .pdf
- IHPA (2009e), Base Catalyzed Decomposition (BCD). Fact sheet prepared by John Vijgen, International HCH and Pesticides Association and Dr. Ir. Ron McDowall, Auckland New Zealand for Secretariat of the Basel Convention. <a href="http://www.ihpa.info/docs/library/reports/Pops/June2009/BCDSBCLogoMainSheetDEFCLEANVERSION 190109">http://www.ihpa.info/docs/library/reports/Pops/June2009/BCDSBCLogoMainSheetDEFCLEANVERSION 190109</a> .pdf

- IHPA (2016). International HCH & Pesticide Association (IHPA) comments on the draft EU-UIP (Union Implementation Plan) in the frame of the Stockholm Convention.
- Jacobs P and Schaffranka, E (2014). Sediment-bound organic pollutants from historical industrial sources in the Spittelwasser creek and their impact on surface water and sediments in the Elbe river basin. Proceedings of the 4<sup>th</sup> International Symposium on Sediment Management.
- Jagnow, G., Haider, K. and Ellwardt, P. (1977). Anaerobic dechlorination and degradation of hexachlorocyclohexane isomers by anaerobic and facultative anaerobic bacteria. Arch. Microbiol. 115, 285–292.
- Joo, S.H., Zhao, D. (2008). Destruction of lindane and atrazine using stabilized iron nanoparticles under aerobic and anaerobic conditions: effects of catalyst and stabilizer. Chemosphere, 70(3):418-25.
- Ju, Y.H., Chen, T.C. and Liu, J.C.A. (1997). Study on the biosorption of lindane. Colloids Surf B Biointerfaces, 9: 187-196.
- Kabra, K., Chaudhary, R. and Sawhney, R.L. (2004). Treatment of Hazardous Organic and Inorganic Compounds through Aqueous-Phase Photocatalysis: A Review. Ind. Eng. Chem. Res., 43: 7683-7696.
- Karstensen, KH. (2013). Experiences from other international processes; Basel and Stockholm convention. In: Launching of Cement Industry Sector Partnership under the UNEP Global Mercury Partnership. <a href="http://www.unep.org/chemicalsandwaste/Portals/9/Dr%20Karstensen%20-%20Final%20Basel%20&%20Stockholm%20%2021%20June%2013.pdf">http://www.unep.org/chemicalsandwaste/Portals/9/Dr%20Karstensen%20-%20Final%20Basel%20&%20Stockholm%20%2021%20June%2013.pdf</a>
- Kips, Ph.A., Stobiecki, S., Bouwknegt, M. and Fokke, B. (2009). Fostering Rudna Landfill in Polland to create possibilities for cost-effective and sustainable rehabilitation. Proceedings from the 10<sup>th</sup> International HCH and Pesticides Forum, Brno, Czech Republic, September 2009, Masarykova univerzita, Brno, pp. 78-83.
- Kouras, A., Zouboulis, A., Samara, C. and Kouimtzis, T. (1998): Removal of pesticides from aqueous solutions by combined physicochemical processes--the behaviour of lindane: Environmental Pollution 103 (2-3): 193-202.
- Krüger, (2016). Website on In situ thermal desorption. http://www.kruger.dk/en/municipalities/insiturem/. Accessed 14 November 2016.
- Kuritz, T. and Wolk C.P. (1995). Use of Filamentous Cyanobacteria for Biodegradation of Organic Pollutants. Applied and Environmental Microbiology, 61 (1): 234–238.
- Lal R., Pandey, G., Sharma,P., Kumari,K., Malhotra,S., Pandey,R., Raina,V., Kohler,HP.E., Holliger,C., Jackson,C. and Oakeshott J.G. (2010). Biochemistry of Microbial Degradation of Hexachlorocyclohexane and Prospects for Bioremediation. Microbiology and Molecular Biology Reviews, Mar. 2010, p. 58–80.
- Langenhoff, A., Staps, S., Pijls, C., Alphenaar, A., Zwiep, G. and Rijnaarts, H. (2001)
   Intrinsic and stimulated in situ biodegradation of Hexachlorocyclohexane (HCH).
   Proceedings from the 6<sup>Th</sup> International HCH and Pesticides, Poznan, Poland, March
   2001, Plant Protection Institute Poznan and IHPA, pp. 181-186.
- Langenhoff A.A.M., Staps S.J.M., Pijls C., Rijnaarts H.H.M. (2013). Stimulation of Hexachlorocyclohexane (HCH) Biodegradation in a Full Scale In Situ Bioscreen. Environ. Sci. Technol. 2013, 47, 11182–11188.
- LIFE (1994). Base cathalyzed dehydrodechlorination of HCH at low temperature.
- LIFE94 ENV/E/001271.

- http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search. dspPage&n\_proj\_id=966&docType=pdf
- LIFE (2012). "DISCOVERED LIFE Lab to field, soil remediation demonstrative project: New ISCO application to DNAPL multicomponent environmental problem" LIFE12 ENV/ES/000761. <a href="http://www.lifediscovered.es/isco-que-es.html">http://en.lifediscovered.es/index.php</a>
- Ludwigshafen am Rhein Website (12 December 2014). Ehemaliges Metrogelände saniert, 12.12.2014.
- http://www.ludwigshafen.de/presse/detail/news/2014/12/12/ehemaligesmetrogelaende-saniert/
- Ludwigshafen am Rhein Website (21 June 2016). Aufwändige Grundwassersanierung geplant.
   21.06.2016.<a href="http://www.ludwigshafen.de/presse/detail/news/2016/06/21/aufwaendige-grundwassersanierung-geplant/">http://www.ludwigshafen.de/presse/detail/news/2016/06/21/aufwaendige-grundwassersanierung-geplant/</a>
- Lunney, A.I., Zeeb, B.A. and Reimer K.J. (2004). Uptake of weathered DDT in vascular plants: potential for phytoremediation. Environ Sci Technol, 38:6147-54.
- Machlica, A. and Chovanec, J. (2015). Chzjd Landfill in Vrakuna the Sleeping Load of Bratislava. Proceedings of the International Conference on Contaminanted Sites. Bratislava, 2015.
- MacRae, I.C., Raghu, K. and Bautista, E.M. (1969). Anaerobic degradation of the insecticide lindane by *Clostridium* sp. Nature 221: 859-860.
- Manickam, N., Mau, M. and Schlomann, M. (2006). Characterization of the novel HCH-degradaing strain, Microbacterium sp. ITRC1. Appl. Microbiol. Biotechnol., 69, 580–588.
- Manickam, N., Misra, R. and Mayilraj, S. (2007). A novel pathway for the biodegradation of γ-hexachlorocyclohexane by a Xanthomonas sp. strain ICH12. J. Appl. Microbiol., 102: 1468–1478.
- Martínez, M. (2016). The Inquinosa Case (Sabiñánigo, Aragón, Spain). Turning an Environmental disaster into opportnities. Management of agro-chemicals: Elimination of "black spots" and creation of "white spots". European Parliament, 29 September 2016.
- Mattson, J.S. and Mark, I.I.B. (1971). Activated carbon surface chemistry and adsorption from aqueous solution, New York: Marcel Dekker.
- Mendes, R., Garbeva, P. and Raaijmakers, J.M. (2013). The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. FEMS Microbiology Reviews, 37 (5): 634–663.
- Merck (2009). Corporate Responsibility Bericht 2009 [Corporate Responsability Report 2009]
  - http://www.merck.de/company.merck.de/de/images/Merck\_CR\_Report\_2009\_DE\_t cm1613\_72012.pdf?Version=&\_ga=1.161353789.1236854330.1474971390
- Merck (2016). Alle Mitteilungen zum Umbau Rheinparkplatz [All communications to rebuild Rhine Parking] Merck Website.
- http://www.merck.de/de/unternehmen/merck in deutschland/standort gernsheim/ umbau rheinparkplatz/alle mitteilungen/alle mitteilungen.html? ga=1.267677838. 1236854330.1474971390. Accessed 11 November 2016.

- Mertens, B., Blothe, C., Windey, K., De Windt, W., Verstraete W. (2007). Biocatalytic dechlorination of lindane by nano-scale particles of Pd(0) deposited on *Shewanella* oneidensis. Chemosphere 66: 99–105.
- Middeldorp, P. J. M., Jasper, M., Zehender, A. J. B., and Schraa, J. (1996). Biotransformation of  $\alpha$ -,  $\beta$ -,  $\gamma$  and  $\delta$ -hexachlorocyclohexane under methanogenic conditions. Environ. Sci. Technol., 30, 2345–2349.
- Ministry of Environment and Forests of Romania. (2010), 2007-2009 Triannual Report on the data and information under Article 12 of Regulation (EC) No 850/2004 on persistent organic pollutants <a href="http://cdr.eionet.europa.eu/ro/eu/colscvkya/envskrka/EN">http://cdr.eionet.europa.eu/ro/eu/colscvkya/envskrka/EN</a> Questionnaire Reg.850-2004 18.05.10.pdf
- Ministry of Environment and Sustainable Development of Romania (2008). 2004-2006
   Triannual Report on the data and information under Article 12 of Regulation (EC) No 850/2004 on persistent organic pollutants.. Available at https://cdr.eionet.europa.eu/ro/eu/colscvkya/envscvlpw/Regulation\_850-2004\_en.doc/manage\_document
- Modell, M., (1990). Treatment of pulp mill sludges by supercritical water oxidation.
   Final Report, DOE Contract No. FG05-90CE40914.
- Mogos, A (2016). Romania, a contaminated country. Contaminated future: <a href="http://contaminatedfuture.org/romania-a-contaminated-country">http://contaminatedfuture.org/romania-a-contaminated-country</a>. Accessed 8 September 2016.
- Mohapatra, S. and Pandey, M. (2015). Biodegradation of Hexachlorocyclohexane (HCH) Isomers by White Rot Fungus, Pleurotus florida. J. Bioremed Biodeg, 6(2).
- Mohn, W.W., Mertens, B., Neufeld, J.D., Verstraete, W. and de Lorenzo, V. (2006). Distribution and phylogeny of hexachlorocyclohexane degrading bacteria in soils from Spain. Environ. Microbiol., 8: 60–68.
- Mougin, C., Pericaud, C. and Dubroca, J. (1997). Enhanced mineralization of lindane in soils supplemented with the white rot basidiomycete Phanerochaete chrysosporium. Soil Biology Biochemistry, 29: 1321-1324.
- Mueller, N.C. and Nowack, B. (2009). Nanotechnology Developments for the Environment Sector - Report of the ObservatoryNANO EU FP7 project. June 2009. www.observatorynano.eu
- Municipality of Turda (n.d). Transforming a polluted site into a green area. Rehabilitation of the Historically Polluted Site - Hazardous Waste Deposit UCT - Poşta Rât (Municipality of Turda): <a href="http://postaratturda.ro/?idpage=1.">http://postaratturda.ro/?idpage=1.</a> Accessed 8 September 2016.
- Nagata, Y., Miyauchi, K. and Takagi, M. (1999). Complete analysis of genes and enzymes for γ-hexachlorocyclohexane degradation in Sphingomonas paucimobilis UT26. J. Ind. Microbiol. Biotechnol., 23: 380–390.
- Nagpal, V., Srinivasan, M.C. and Paknikar, K.M. (2008). Biodegradation of I3-hexachlorocyclohexane (Lindane) by a non-white rot fungus conidiobolus 03-1- 56 isolated from litter. Indian J Microbiol, 48: 134-141.
- Nagpal, V., Bokare, A.D., Chikate, R.C., Rode, C.V. and Paknikar, K.M. (2010).
   Reductive dechlorination of γ-hexachlorocyclohexane using Fe-Pd bimetallic nanoparticles. Journal of Hazardous Materials 175: 680-687.

- Nawab, A., Aleem, A. and Malik, A. (2003). Determination of organochlorine pesticides in agricultural soil with special reference to γ-HCH degradation by Pseudomonas strains. Bioresour. Technol., 88: 41–46.
- Noticias de Álava (17 August 2016a). El Zadorra arrastra residuos de lindano desde hace tres años. <a href="http://www.noticiasdealava.com/2016/08/17/araba/el-zadorra-arrastra-residuos-de-lindano-desde-hace-tres-anos">http://www.noticiasdealava.com/2016/08/17/araba/el-zadorra-arrastra-residuos-de-lindano-desde-hace-tres-anos</a>
- Noticias de Álava (21 September 2016b). A vueltas con el lindano. http://www.noticiasdealava.com/2016/09/21/araba/a-vueltas-con-el-lindano
- NRC, (1996). Review and Evaluation of Alternative Chemical Disposal Technologies. Panel on Review and Evaluation of Alternative Chemical Disposal Technologies, Edited by the National Research Council.

https://www.nap.edu/read/5274/chapter/8

- Ocelka, T., Pekarek, V. and Nikl, S. (2009). Application of Copper Mediated Destruction for pilot remediation for Jaworzno site. <a href="http://projectfoks.zuova.cz/wp-content/uploads/2009/07/7">http://projectfoks.zuova.cz/wp-content/uploads/2009/07/7</a> t ocelka application of copper mediated destruction for pilot remediation for jaworzno site.pdf
- Okeke, B,C., Siddique, T., Arbestain, M.C., and Frankenberger, W.T. (2002). Biodegradation of gamma-hexachlorocyclohexane (lindane) and alpha-hexachlorocyclohexane in water and a soil slurry by a Pandoraea species. J. Agric. Food Chem., 50, 2548–2555.
- Oltchim, S.A. (2007). History. Oltchim SA: <a href="http://www.oltchim.ro/en/index.php?name=about-us/history">http://www.oltchim.ro/en/index.php?name=about-us/history</a>. Accessed 7 September 2016.
- Ortega, S. (2016). Megasite as burden and challenge for Regional Government of Aragon. Management of agro-chemicals: Elimination of "black spots" and creation of "white spots". European Parliament 29 September 2016.
- OSPAR. (2002). Lindane, Hazardous Substances Series. OSPAR Commission. http://www.ospar.org/documents?v=6951
- Osterhuis, F. and Browver, R. (2015). Benchmark development for the proportionality assessment of PBT and vPvB substances. IVM Institute for environmental Studies. <a href="https://echa.europa.eu/documents/10162/13647/R15">https://echa.europa.eu/documents/10162/13647/R15</a> 11 pbt benchmark report en.pdf
- Otani, T., and Seike, N. (2006). Comparative effects of rootstock and scion on dieldrin and endrin uptake by grafted cucumber (Cumis sativus). J Pestic Sci, 31: 316-21.
- Ozola (personal comunication). Answers to the questionnaire. See Annex II of this document.
- Pál, J. and Simon, G. (2006). Lindane in Hungary. International POPs Elimination project: Hungary, 2006.
- Paun, MC (personal communication). Answers to the questionnaire. See Annex II of this document.
- Pethö, A. and Ocskó, Z. (2003). POP Hatóanyagot Tartalmazó Növényvédőszerek Hazai Felhasználása1950-2000 [Plant protection products for domestic use containing POP active substances 1950-2000]. Budapest, 2003.
- Pethö, A. (personal comunication). Answers to the questionnaire. See Annex II of this document.

• Phillips, T.M., Seech, A.G., Lee, H. and Trevors, J.T. (2005). Biodegradation of hexachlorocyclohexane (HCH) by microorganisms. Biodegradation 16: 363–392.

- Pllard, S.J.T, Fowler, G.D., Sollars, C.J. and Perry, R. (1992). Low Cost adsorbents for waste and wastewater treatment. Sci. Total Environ., 116: 31-52.
- POPRC (Persistent Organic Pollutants Review Committee) (2006). Report of the Persistent Organic Pollutants Review Committee on the work of its second meeting – Risk profile on lindane (UNEP/POPS/POPRC.2/17/Add.4). Second meeting
- http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC2/POPR C2documents/tabid/106/Default.aspx
- POPRC (Persistent Organic Pollutants Review Committee), (2007). Report of the Persistent Organic Pollutants Review Committee on the work of its third meeting – Risk management evaluation on lindane (UNEP/POPS/POPRC.3/20/Add.4). Third meeting
- http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC3/POPR C3documents/tabid/77/Default.aspx
- Ratola, N., Botelho, C. and Alves, A. (2003). The use of pine bark as a natural adsorbent for persistent organic pollutants–study of lindane and heptachlor adsorption. J Chem Technol Biotechnol, 8: 347-351.
- Rodriguez, B. (2009). Movilidad, biodisponibilidad y degradación inducida de isómeros de Hexaclorociclohexano (HCH) en suelos contaminados. [Mobility, bioavailability and induced degradation of HCH in contaminated soils.] Tesis doctoral. Universidad de Santiago de Compostela.
- Royal Decree, (2005). Real Decreto 9/2005, de 14 de enero, por el que se establece la relación de actividades potencialmente contaminantes del suelo y los criterios y estándares para la declaración de suelos contaminados. Boletín Oficial del Estado 15/2005, 1833-1843.
- Ruzzenenti, M. (2013). Valle del Sacco. Industria e Ambiente: <a href="http://www.industriaeambiente.it/schede/valle del sacco/">http://www.industriaeambiente.it/schede/valle del sacco/</a>. Accessed 6 September 2016.
- Salam, JA. and Das, N. (2012). Remediation of lindane from environment An overview. International Journal of Advanced Biological Research, 2(1): 9-15.
- Salam, JA. and Das, N. (2013). Biosorptive removal of lindane using pretreated dried yeast *Cintractia sorghi* VITJZN02 equilibrium and kinetics studies. International Journal of Pharmacy and Pharmaceutical Sciences, 5(3): 987-993.
- Salas, O., Gascón, J.A., Susaeta, I. 1999. Treatability studies on solvent extraction technologies: Bench scale evaluation. Proceedings from the 5th International HCH and pesticides Forum, Bilbao, Spain, June 1998, IHOBE, pp. 153-158.
- SE (Suez Environment). (2006). SPOLANA, Setting the example for depollution in the Czech Republic. <a href="http://www.suez-environnement.fr/wp-content/uploads/2008/07/eec6386e0276f61088ec3b9750f7b664.pdf">http://www.suez-environnement.fr/wp-content/uploads/2008/07/eec6386e0276f61088ec3b9750f7b664.pdf</a>
- Senthilnathan, J. and Philip, L. (2010). Photocatalytic degradation of lindane under UV and visible light using N-doped TiO2. Chemical Engineering Journal, 161: 83–92.
- Shelton, D.R., Khader, S., Karns, J.S. and Pogell, B.M., (1996). Metabolism of twelve herbicides by Streptomyces. Biodegradation 7, 129–136.

- Siddique, T., Okeke, B.C., Arshad, M. and Frankenberger, W.T. Jr (2002). Temperature and pH effects on biodegradation of hexachlorocyclohexane isomers in water and soil slurry. J Agric Food Chem, 50:5070–5076.
- Simon, G.. (personal com). Answers to the questionnaire and personal communication. See Annex II of this document.
- Sineli, P. E., Tortella, G., Da'vila Costa, J. S., Benimeli, C. S., Cuozzo S. A. (2016). Evidence of α-, β- and Y-HCH mixture aerobic degradation by the native actinobacteria Streptomyces sp. M7. World J Microbiol Biotechnol 32:81.
- Singh, B.K. and Kuhad, R.C. (1999). Biodegradation of lindane (gamma-hexachlorocyclohexane) by the white-rot fungus *Trametes hirsutus*. Lett Appl Microbiol., 28:238–241.
- Singh, R., Singh, A., Misra, V., Singh R.P. (2011). Degradation of lindane contaminated soil using zero-valent iron nanoparticles. J Biomed Nanotechnol., 7(1):175-6.
- Slovak Spectator, the (2016). Solving an unpleasant legacy at last. <u>http://spectator.sme.sk/c/20087696/solving-an-unpleasant-legacy-at-last.html</u>.
   Accessed 2 November 2016.
- SOC. 1993. Shell Oil Company. In-situ thermal desorption of contaminated surface soil. Patent: US 5193934 A. <a href="http://www.google.com/patents/US5193934">http://www.google.com/patents/US5193934</a>
- Song, H. and Carraway, E. (2005). Reduction of chlorinated ethanes by nanosized zero-valent iron: Kinetics, pathways, and effects of reaction conditions. Environmental Science & Technology 39(16).
- SSC (Spanish Supreme Court) (1993). Environmental crime. <a href="http://www.camarazaragoza.com/medioambiente/docs/jurisprudencia/juri
- Steith (2012). Démantèlement et Réhabilitation de la Station de Traitement des Eaux Industrielles de Huningue. <a href="http://sanierung-steih.ch/wp-content/uploads/2013/10/1206">http://sanierung-steih.ch/wp-content/uploads/2013/10/1206</a> Huningue STEIH Reunion Publique 25Jun12.pdf Accessed 12 September 2016.
- Steith. (2016). Website on the remediation of the ARA STEIH site. <a href="http://sanierung-steih.ch/en/">http://sanierung-steih.ch/en/</a>. Accessed 4 November 2016.
- Stobiecki, S., Waleczek, K., Stobiecki, T. and Stadniczuk, M. (2009). The biggest POP clean up problem in Poland-"Rudna Gora" industrial landfill for hazardous waste. Proceedings from the 10<sup>th</sup> International HCH and Pesticides Forum, Brno, Czech Republic, September 2009, Masarykova univerzita, Brno, pp. 72-77.
- Stobiecki, T. and Sobiecki, S. (2011). "Rudna Gora" landfill in Jaworzno the present legal and organizational situation. Proceedings from the 11<sup>th</sup> International HCH and Pesticides Forum, Gabala, Azerbaijan, September 2011, IHPA and UNEP, pp. 259-263.
- Stobiecki, T. (2013). Case Study: Rudna Góra, Jawarzno, Poland.Workshop: "Breaking the Infinite Assessment Cycle of POP Pesticides Dumpsites". 12th International HCH and Pesticides Forum, Kiev, Ukraine, November 2013.
- Thomason, T.B., Hong, G.T., Swallow, K.C. et al., (1990). The MODAR supercritical water oxidation process. In: Innovative hazardous waste treatment technology series
- (Freeman H.M., ed.). Lancaster, PA: Technomic Publishing. Volume I: Thermal Processes.

- Ecologistas en Acción (personal communication): Informe sobre dioxinas y furanos en los residuos de Inquinosa. [Report on dioxins and furans in wastes from Inquinosa]. Técnicas de Protección Ambiental 1991.
- Tsezos, M. and Bell, JP. (1989). Comparison of the biosorption and desorption of hazardous organic pollutants by live and dead biomass. Water Res, 23: 561-568.
- Tsitonaki, A., Petri, B., Crimi, M., Mosbaek, H, Siegrist, R. L. and Bjerg, P. L. (2010).
   In situ chemical oxidation of contaminated soil and groundwater using persulfate: a review. Critical Reviews in Environmental Science and Technology, 40 (55).
- Ucer, A., Uyanik, A. and Aygun, S.F. (2006). Adsorption of Cu (II), Cd (II), Zn (II), Mn (II) and Fe (III) ions by tannic acid immobilised activated carbon, Sep. and Pur. Tech., 47: 113-118.
- van Hasselt, H.J., Costerus, A., Rulkens, W.H. (1998). Developments and operating experience in soil cleaning: Thermal treatment of soils contaminated with HCH's, and solvent extraction of soil contaminated with HCH's. Proceedings from the 5th International HCH and pesticides Forum, Bilbao, Spain, June 1998, IHOBE, pp. 131-143.
- Varela-Castejón, C and Martinez, F. (2008). Antecedentes históricos sobre la contaminación por lindano en O Porriño (Pontevedra). Edafología, 15 (1-3): 25-32. http://edafologia.ugr.es/Revista/tomo15/articulo25.pdf
- Veriansyah, B.and Kim, J-D. (2007). Supercritical water oxidation for the destruction of toxic organic wastewaters: A review. Journal of Environmental Sciences 19: 513– 522.
- Vidal, A. (1998). Developments in solar photocatalysis for solar purification. Chemosphere 36: 2593-2606.
- Vijgen J. (2006). The Legacy of Lindane HCH Isomer Production. Main Report. A Global Overview of Residue Management, Formulation and Disposal. International HCH & Pesticides Association.
- Vijgen, J. (2016). Large contaminations at two former Lindane production plants.
   IHPA: <a href="http://www.ihpa.info/info/2016/06/08/large-contaminations-at-two-former-lindane-production-plants/">http://www.ihpa.info/info/2016/06/08/large-contaminations-at-two-former-lindane-production-plants/</a>. Accessed 14 September 2016.
- Vijgen, J. and MacDowall, R. (2009). Base Catalyzed Decomposition Provisional POPs Technology Specification and Data Sheets for the Secretariat of the Basel Convention. http://www.ihpa.info/docs/library/reports/Pops/June2009/BCDSBCLogoMainSheetD EFCLEANVERSION 190109 .pdf
- Vijgen, J., Abhilash, P.C., Li, Y.F., Lal, R., Forter, M., Torres, J., Singh, N., Yunus, M., Tian, C., Schäffer, A. and Weber, R. (2010). HCH isomers as new Stockholm Convention POPs—are we on the way to manage lindane (γ-HCH), and waste HCH isomer (a- and β-HCH) pollution around the world? Environ Sci Pollut Res, 5:363–393.
- Vijgen, J., Abhilash, P. C., Li Y.F., Lal, R., Forter, M., Torres, J., Singh, N., Yunus, M., Tian, G. and Schäffer, A. (2011). Hexachlorocyclohexane (HCH) as new Stockholm Convention POPs—a global perspective on the management of Lindane and its waste isomers, Environmental Science and Pollution Research Vol. 18(2), 152- 162
- Violeta, S.C. and Dobrin, M. (2010). Remediation Measures for Posta Râ t Contaminated Site (Turda). ProEnvironment Promediu, 3(5): 37-43.

- Vytopilova (personal communication). Ministry of Environment. Czech Republic. Answers to the questionnaire. See Annex II of this document.
- Wallbaum, E. and Fuchs, W. (1993). Environmental pollution as a consequence of HCH production in Sachsen Anhalt. A situation report. International HCH and halogenated pesticides Forum. Complilation of 1st Forum - 1991, Zwolle, The Netherlands and 2nd Forum - 1992, Magdeburg, Germany.
- Weber, R. (2004). Relevance of PCDD/PCDF Formation for the Evaluation of POPs Destruction Technologies. Necessity and Current Status". Organohalogen Compounds Volume 66: 1273-1280. http://www.coprocem.com/documents/weberr-2004 popsdestr-pcddf-form.pdf
- Weber, R. and Varbelow, H.G. (2013). Dioxin/POPs legacy of pesticide production in Hamburg:Part 1—securing of the production area. Environ Sci Pollut Res, 20:1918–1924.
- Westcott, N.D. and Worobey, B.L. (1985). Novel solvent extraction of lindane from soil. J. Agric. Food Chem., 33 (1): 58–60.
- Whitfield Aslund, M.L., Lunney, A.I., Rutter, A. and Zeeb, B.A. (2010). Effects of amendments on the uptake and distribution of DDT in *Cucurbita pepo* ssp pepo plants. Environ Pollut, 158: 508-13.
- WHO (1991). IPCS International Programme on Chemical Safety. Health and Safety Guide No. 54 Lindane (gamma-HCH) health and safety guide. United Nations Environment Programme. International Labour Organisation. World Health Organization. Geneva, 1991. http://www.inchem.org/documents/hsg/hsg/hsg054.htm
- Wiszniewska, A., Hanus-Fajerska, E., Muszynska, E. and Ciarkowska, K. (2016).
   Natural Organic Amendments for Improved Phytoremediation of Polluted Soils: A Review of Recent Progress. Pedosphere, 26(1): 1–12.
- Wycisk, P., Stollberg, R., Neumann, C., Gossel, W., Weiss, H. and Weber, R. (2013). Integrated methodology for assessing the HCH groundwater pollution at the multi-source contaminated mega-site Bitterfeld/Wolfen. Environ Sci Pollut Res, 20:1907–1917.
- Zaleska, A., Hupka, J., Wiergowski, M. and Biziuk, M. (2000). Photocatalytic degradation of lindane, p,p'-DDT and methoxychlor in an aqueous environment. Journal of Photochemistry and Photobiology A: Chemistry, 135 (2–3): 213–220.
- Zhao, X., Quan, X., Chen, S., Zhao, H.M. and Liu Y (2007). Photocatalytic remediation of gamma-hexachlorocyclohexane contaminated soils using TiO2 and montmorillonite composite photocatalyst. J Environ Sci (China), 19(3):358-61.
- Zheng, G., Selvam, A., Wong, J.W.C. (2011). Rapid degradation of lindane (g-hexachlorocyclohexane) at low temperature by Sphingobium strains. International Biodeterioration & Biodegradation 65: 612-618.
- Abhilash, P.C., Srivastava, S., Srivastava, P., Singh, B., Jafri, A. and Singh, N. (2011). Influence of rhizospheric microbial inoculation and tolerant plant species on the rhizoremediation of lindane. Environmental and Experimental Botany, 74:127– 130.

#### Annex I. Answers to Questionnaires

The following answers to questionnaires have been received.

- Ministry of the Environment of the Czech Republic
- Danish Environmental Protection Agency
- National Food Chain Safety Office of Hungary
- Ministry of Environmental Protection and Regional Development of Latvia
- Ministry of Environment, Water and Forests of Romania
- Ministry of Agriculture, Food and Environment of Spain
- Secretary of Environmental Administration od the Basque Country, Spain
- ASDEN
- Green Cross
- Greenpeace Central and Eastern Europe (CEE)
- Martin Forter, Independent scientist for municipalities, residents and environmental organisations
- Tauw by
- UFZ-Department of Isotope Biogeochemistry Helmholtz Centre for Environmental Research

#### Czech Republic

Contact name: Michaela Vytopilova e-mail: Michaela.Vytopilova@mzp.cz Institution/Organization: Ministry of the Environment **Country: Czech Republic** ⊠Yes □No 1. Are you aware of any (historic) lindane production site in your country? If "yes", please provide information on the plants, locations and/or any reference/web-link/contact person regarding this information. SPOLANA Ltd., ulice Práce 657, 277 11 Neratovice http://www.spolana.cz/En/AboutUs/Pages/default.aspx contact person: Ms. Zuzana Komárková +420 315 663 542 tel.: zuzana.komarkova@spolana.cz e-mail: We would also appreciate any reference/web-link/contact person regarding any (historic) production site in other EU Member state. Chemické závody Juraja Dimitrova, Dimitrovova 34, Bratislava, Slovakia 2. Are you aware of any lindane disposal, dumping or ⊠Yes □No polluted sites in your country? If "yes", please provide information on the site and its location and/or any reference/web-link/contact person regarding this information. There is a database of contaminated sites in CZ http://www.sekm.cz/ (only in Czech) more info: Mr. Jan Gruntorád, Ministry of the Environment tel: +420 267 122 785, +420 606 626 618 jan.gruntorad@mzp.cz 3. Do you have experience on technologies or best ⊠Yes □No practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane) If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) on this issue?? (in your county or at international level) .... more info: Mr. Jan Gruntorád, Ministry of the Environment tel: +420 267 122 785, +420 606 626 618 <u>Jan.Gruntorad@mzp.cz</u>

4. Do you have experience on de-pollution contaminated soils and/or aquatic compart		⊠Yes	□No
If "yes", can you briefly explain your experience references/web-links/contact persons) regarding compartments (soil and surface/ground water/selindane?	de-pollution	of enviror	nmental
Mr. Jan Gruntorád, Ministry of the Environment			
tel: +420 267 122 785, +420 606 626 618			
Jan.Gruntorad@mzp.cz_and			
Mr. Lukáš Čermák, MoE			
Tel: +420 267 122 791, +42 602 111 881 <u>Lukas</u>	s.Cermak@m	ızp.cz	
5. Do you have any experience on lindane w treatment?	vaste	⊠Yes	□No
If "yes", can you briefly explain your experience references/web-links/ contact persons) on lindar residues?	•		•
Stocks of Obsolete Pesticides were mainly disposincineration in the 1990s	sed by high t	emperatur	e
6. Regarding information to citizens, is ther official website providing information or cal hazardous chemicals (and specifically on lir your country?	mpaign on	⊠Yes	□No
In case of "yes", please provide the web-link:			
http://www.recetox.muni.cz/nc/index-en.php			
http://www.genasis.cz/index-en.php			
http://www.irz.cz			
http://arnika.org/lindan-gama-hch (NNO)			
In case the information is not in English, please on hazardous chemicals is provided:	specify what	kind of inf	ormation
- Health and/or environmental risks	⊠Yes	□No	
- Polluted sites	⊠Yes	□No	
- Exposure through articles and/or food and sources	d/or other ⊠Yes	□No	
- Environmental and human monitoring date	ta: ⊠Yes	□No	
- Recommendations to reduce exposure	⊠Yes	□No	
- Regulations and policies	⊠Yes	□No	
- Links to other websites	⊠Yes	□No	

id_numb er	Location	Description	concentration in groundwater (µg/L)	max concentration in surface water (µg/L)	max concentration in soil mg/kg dry weight	Current status	Current status
888002	Božice	storage of pesticides			0,000732	needs to be remediated	12/10/2015 12:06
1316003		former barrack of the Soviet army	0,00971			remediation was finished	04/04/2013 17:10
1527001	Běchovice	former landfill			0,000169	no remediation is needed	29/11/2012 13:21
1666001	Bystré u Poličky	former landfill	0,00007			remediation was finished	10/12/2009 15:08
2053002		well formerly used for waste deposition	0,000013		0,263	remediation was finished	29/10/2009 16:15
2261001	Hodonín u Nasavrk	landfill	0,0141			remediation was finished	25/05/2016 8:31
	Hroznětín	former landfill of waste from lindane production	0,1402		0,000922	needs to be remediated	20/01/2010 14:38
5919001		former landfill	0,0406	0,00006		remediation was finished	14/01/2016 8:24
	Otín u Jindřichova Hra				0,0314	needs to be remediated	12/10/2015 10:21
6541003	Kladruby nad Labem	landfill of hazardous sludges			0,000032	needs to be remediated	20/07/2012 16:43
6579008	Luby	former storage of pesticides			0,01	remediation was finished	26/06/2013 15:03
6759001	Koclířov	former landfill	0,00004			further monitoring is needed	09/12/2009 18:41
7112001	Kotvrdovice	former landfill		0,00001		further monitoring is needed	12/11/2009 9:47
9000001	Makov u Litomyšle	former landfill	0,00004			remediation was finished	11/12/2009 14:14
9244002	Nedaničky	former landfill of urban waste	0,164			further monitoring is needed	11/01/2010 17:15
10356001	Neratovice	SPOLANA a.s., chemical plant	15,515995	0,00062	0,56	remediation is ongoing	03/03/2016 8:50
10630001	Nové Hrady u Skutče	agricultural production		0,000019		remediation is not needed	03/06/2013 14:54
10788001	Nový Rychnov	former landfill of hazardous waste	0,09999			remediation was finished	27/07/2015 15:23
11265001	Ořechov u Uherského	landfill			0,000005	further monitoring is needed	29/01/2016 15:07
11765002	Dražkovice	landfill	0,00036			remediation was finished	26/07/2010 10:09
12169030	Pleše	agricultural production			0,00004	remediation was finished	18/11/2015 9:16
13284001	Prameny	former agricultural site	0,0095			remediation is ongoing	20/01/2010 11:20
13385001	Protivín	ZEKO Protivín, industrial site	0,000018			remediation was finished	04/11/2014 15:46
14638001	Pohora	landfill	0,00001			needs to be remediated	10/12/2009 14:41
14793001		Smržov - Číbuz, landfill of urban waste	0,00001			further monitoring is needed	22/10/2009 16:16
14979001	Slatiňany	EURO - Šarm spol.s.r.o., storage of chemicals	0,000003			further monitoring is needed	14/12/2009 9:37
	Nové Strakonice	Strakonický castle - cellars (former storage of agrochemicals)	0,00002			remediation was finished	18/10/2012 16:42
17487004		Spolchemie a.s., chemical plant			0,000341	needs to be remediated	18/11/2015 8:44
18348002	Vlastislav	AGROSONEP SKALKA s.r.o., agricultural production			0,0015	remediation is progressing	30/09/2010 9:07
	Vranová Lhota	extractive gallery formerly used for waste storage	0,000528			further monitoring is needed	12/11/2009 16:10
		former storage of pesticides				remediation was finished	21/11/2011 16:57
19496002	Zdánice	former landfill	0,002	91		further monitoring is needed	11/11/2009 10:45

53785001 Stará Libavá	landfill	0,000002		will be remediated	19/02/2012 11:33
72313001 Týnec u Janovic nad Ú	castle, former storage of pesticides	0,0608	0,000048	remediation was finished	15/12/2015 16:11

### **Denmark**

Contact name: Lene Gravesen						
e-mail: lgr@mst.dk						
Institution/Organization: Danish Environmental Protection Agency						
Country: Denmark						
1. Are you aware of any (historic) lindane production site in your country?	□Yes	⊠No				
If "yes", please provide information on the plants, locations and/or any reference/web-link/contact person regarding this information						
We would also appreciate any reference/web-link/contact per (historic) production site in other EU Member state	rson regard	ing any				
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	□Yes	⊠No				
If "yes", please provide information on the site and its location and/or any reference/web-link/contact person regarding this information						
3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	□Yes	⊠No				
If "yes", can you briefly explain your experience or provide in references/web-links/contact persons) on this issue?? (in you international level)						
4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?	□Yes	⊠No				
If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) regarding de-pollution of environmental compartments (soil and surface/ground water/sediments) contaminated with lindane?						
5. Do you have any experience on lindane waste treatment?	□Yes	⊠No				
If "yes", can you briefly explain your experience or provide information (also references/web-links/ contact_persons) on lindane treatment methods and residues?						
Lindane has been banned I Denmark since 1994. It is believe lindane containing pesticides has been disposed of to a plant hazardous waste.						

6. Regarding information to citizens, is official website providing information of hazardous chemicals (and specifically cyour country?	ın on	□Yes	⊠No	
In case of "yes", please provide the web-lin	k:			
In case the information is not in English, ple on hazardous chemicals is provided:	ease specify	/ what	kind of i	nformation
Health and/or environmental risks	□Yes	□No		
Polluted sites	□Yes	□No		
Exposure through articles and/or food and/o sources	or other □Yes	□No		
Environmental and human monitoring data:	□Yes	□No		
Recommendations to reduce exposure	□Yes	□No		
Regulations and policies	□Yes	□No		
Links to other websites	□Yes	□No		
In case of "No", please indicate the reasons	, if any			

## Hungary

Contact name: Ágnes Pethő dr.						
e-mail:pethoa@nebih.gov.hu						
Institution/Organization:National Food Chain Safety Of	fice					
Country:Hungary						
Are you aware of any (historic) lindane production site in your country?	□Yes	XNo				
If "yes", please provide information on the plants, locations and/or any reference/web-link/contact person regarding this information.						
Earlier the lindane was produced by Hungarian companies						
Nitrokémia between 1962-1975 Budapesti Vegyi Művek (Chemical Company, Budapest) between 1961-1978 Csepeli és Komáromi Kőolajipari Vállalat (Petrolchemical Company of Csepel and Komárom) between 1963-67						
We would also appreciate any reference/web-link/contact person regarding any (historic) production site in other EU Member state.						
Earlier production sites						
1. Azot (PL) 1968-1992						
2. 2. VEB (NDK) 1960-1992						
3. Rhone-Poulenc (FR) 1988-1992						
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	□Yes	ХNо				
If "yes", please provide information on the site and its location reference/web-link/contact person regarding this information.		ıy				
3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	□Yes	XNo				
If "yes", can you briefly explain your experience or provide in references/web-links/contact persons) on this issue?? (in you international level)	•					
4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?	□Yes	ΧNο				
If "yes", can you briefly explain your experience or provide in references/web-links/contact persons) regarding de-pollution compartments (soil and surface/ground water/sediments) conlindane?	of environr	mental				

5. Do you have any experience on linda treatment?	□Yes	ХNо		
If "yes", can you briefly explain your experiences/web-links/ contact_persons) on linesidues?	•			`
6. Regarding information to citizens, is official website providing information of hazardous chemicals (and specifically cyour country?	gn on	X Yes	□No	
In case of "yes", please provide the web-lin	k:			
http://okbi.hu/page.php?trid=6;				
http://www.greenpeace.org/hungary/hu/				
http://reflexegyesulet.hu/index.php/nulla-h	<u>ulladek</u>			
http://www.ecotox.hu/ecotox2/index.php				
In case the information is not in English, ple on hazardous chemicals is provided:	ease specit	fy what	kind of inf	ormation
Health and/or environmental risks	X Yes	□No		
Polluted sites	□Yes	□No		
Exposure through articles and/or food and/o sources	or other □Yes	□No		
Environmental and human monitoring data:	□Yes	□No		
Recommendations to reduce exposure	XYes	□No		
Regulations and policies	XYes	□No		
Links to other websites	□Yes	□No		
In case of "No", please indicate the reasons	, if any			

#### Latvia

De: Daina Ozola [mailto:Daina.Ozola@varam.gov.lv]

Enviado el: lunes, 19 de septiembre de 2016 12:37

Para: vega@era-consult.com

Asunto: FW: Questionnaire on lindane: EU mapping and depollution techniques

#### Dear Ms Vega,

My colleague kindly forwarded your e-mail received last week on lindane mapping and depolluting issues.

Let me inform you that none of POPs pesticides including lindane never has been produced in Latvia. Since Year 1999 use of lindane is prohibited. However information given in National Action Programme on Persistent Organic Pollutants 2005 – 2020 shows that 49 t of lindane were imported in period 1995 – 1999. Lindane was used as insecticide of complex exposure to combat insecticides in activities like coppices, non-producing orchards and cereals.

Saying this I would like to let you know that we do not have any information to provide in shape questionnaire is asking for.

Kind regards,

Daina Ozola

Head of the Pollution Prevention Division

**Environment Protection Department** 

Ministry of Environmental Protection and Regional Development

Republic of Latvia

Phone: +37167026516

Contact name: Ruta Rimsa				
e-mail: Ruta.Rimsa@varam.gov.lv				
Institution/Organization: Ministry of Environmental Protection and Regional Development				
Country: Latvia				
1. Are you aware of any (historic) lindane production site in your country?	□Yes	⊠No		
If "yes", please provide information on the plants, locations and/or any reference/web-link/contact person regarding this information				
We would also appreciate any reference/web-link/contact per (historic) production site in other EU Member state	rson regardi	ing any		
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	□Yes	⊠No		

If "yes", please provide information on the streference/web-link/contact person regarding				any
3. Do you have experience on technology practices regarding the dismantling and of polluted production sites? (not only plindane)	□Yes	⊠No		
If "yes", can you briefly explain your experiences/web-links/contact persons) on the international level)	•			•
4. Do you have experience on de-pollut contaminated soils and/or aquatic com			□Yes	⊠No
If "yes", can you briefly explain your experiences/web-links/contact persons) regard compartments (soil and surface/ground wat lindane?	rding de-po	llution	of enviro	nmental
5. Do you have any experience on linda treatment?	ne waste		□Yes	⊠No
If "yes", can you briefly explain your experiences/web-links/ contact_persons) on linesidues?	•			•
6. Regarding information to citizens, is official website providing information of hazardous chemicals (and specifically of your country?  In case of "yes", please provide the web-line.	r campaig on lindane	n on	⊠Yes	□No
State Ltd "Latvian Environment, Geology and Metehttp://www.lvgmc.lv/lapas/vide/vide?id=11	eorology Cer		ebsite:	
In case the information is not in English, ple on hazardous chemicals is provided:	ease specify	what	kind of in	formation
Health and/or environmental risks	□Yes	□No		
Polluted sites	⊠Yes	□No		
Exposure through articles and/or food and/o sources	or other □Yes	□No		
Environmental and human monitoring data:	⊠Yes	□No		
Recommendations to reduce exposure	□Yes	□No		
Regulations and policies	⊠Yes	□No		
Links to other websites	⊠Yes	□No		
NOTE: through links to other websites it is printed information not provided directly in website		find ot	her impor	tant
In case of "No", please indicate the reasons	, ir any			

# Study on "Lindane (Persistant Organic Pollutant) in the EU"

In order to compile information on lindane production and dumping sites in Europe, as well as best practices in de-pollution techniques, we would appreciate your contribution to the following questions.

Contact name: Mihaela Claudia Paun, Senior Policy Adviser e-mail: mihaela.ciobanu@mmediu.ro Institution/Organization: Ministry of Environment, Water and Forests						
					Country: Romania	
					1. Are you aware of any (historic) lindane production site in your country?	⊠Yes □No
At the national level there were two companies producing Lindane:						
a) SC Oltchim SA – produced Lindane between 1969 to 2006; the history of the company can be found at the following link:						
http://www.oltchim.ro/en/index.php?name=about-us/history						
b) Turda Chemical Plants (U.C.T.) – produced Lindane during the period 1954 -1983; the plants activity was ceased in 1998.						
According to the 2004-2006 Triannual Report on the data and information under Article 12 of Regulation (EC) No 850/2004 on persistent organic pollutants, Romania produced 90,000 Kg of Lindane in 2005 and 12,000 Kg in 2006. Romania exported to Spain 7,800 kg of Lindane in 2005 and 12,000 kg in 2006. The report is available at the following link: <a href="http://cdr.eionet.europa.eu/ro/eu/colscvkya/envscvlpw/Regulation 850-2004">http://cdr.eionet.europa.eu/ro/eu/colscvkya/envscvlpw/Regulation 850-2004</a> en.doc/manage document						
We would also appreciate any reference/web-link/contact person regarding any (historic) production site in other EU Member state.						
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	⊠Yes □No					
According to the inventory, there are no stockpiles of Lindane a 2010 was the last date when a stockpile of Lindane was identifie Lindatox (containing 20% Lindane), kept by an economic operator plant protection products. Following the checking performe	d, namely 563 kg or in a storehouse					

Environmental Guard and the local authorities, the holder of the stockpile eliminate

it through specialized company in May 2010 (source: 2007-2009 Triannual Report on the data and information under Article 12 of Regulation (EC) No 850/2004 on persistent organic pollutants http://cdr.eionet.europa.eu/ro/eu/colscvkya/envskrka/EN Questionnaire Reg.850-2004 18.05.10.pdf). Regarding the polluted sites, according to the preliminary inventory of contaminated sites conducted at the national level, in Romania were identified 7 potential contaminated sites with hexachlorocyclohexane (HCH). Three of these sites are localized at SC Oltchim SA, and the other four potentially contaminated sites are localized on the platform of former Turda Chemical Plants (U.C.T.). 3. Do you have experience on technologies or best ⊠Yes □No practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane) On the former Turda Chemicals Plants was conducted the project "Rehabilitation of the Historically Polluted Site - Hazardous Waste Deposit U.C.T. - Posta Rât". Details about the project can be found at the following link: http://postaratturda.ro/?lang=en 4. Do you have experience on de-pollution of lindane ⊠Yes □No contaminated soils and/or aquatic compartment? Please see the information provided on Question 3 above. □Yes ⊠No 5. Do you have any experience on lindane waste treatment? If "yes", can you briefly explain your experience or provide information (also references/web-links/ contact\_persons) on lindane treatment methods and residues? 6. Regarding information to citizens, is there any official ⊠Yes □No website providing information or campaign on hazardous chemicals (and specifically on lindane) in your country? In case of "yes", please provide the web-link: Website of Ministry of Environment, Water and Forests: http://www.mmediu.ro/categorie/pop-s/58 Website of National Environment Protection Agency: http://www.anpm.ro/poluanti-organici-persistenti-pops-In case the information is not in English, please specify what kind of information on hazardous chemicals is provided:

-	Health and/or environmental risks	⊠Yes	□No	
-	Polluted sites	□Yes	□No	
-	Exposure through articles and/or food and/sources	or other □Yes	□No	
-	Environmental and human monitoring data	: □Yes	□No	
-	Recommendations to reduce exposure	⊠Yes	□No	
-	Regulations and policies	⊠Yes	□No	
-	Links to other websites	□Yes	□No	
In case of "No", please indicate the reasons, if any				

#### Spain

Contact name: Ana García Gonzalez

e-mail: aggonzalez@magrama.es

Institution/Organization: Ministry of Agriculture, Food and Environment

Country: Spain

## 1. Are you aware of any (historic) lindane production

site in your country?

⊠Yes □No

If "yes", please provide information on the plants, locations and/or any reference/web-link/contact person regarding this information.

#### País Vasco:

Insecticidas Condor in Baracaldo (Vizcaya) founded in 1944. It was divided into two companies in 1960:

Insecticidas Condor. It was translated to Amorebieta (Vizcaya). It was closed in 1985.

Standar Química, in Baracaldo (Vizcaya). Later, in 1983, becomes Cielmar España. Finally, in 1985, the company changed its name to Bilbao Chemicals and it was closed in 1987.

Nexana Celamerck, in Asua (Vizcaya) founded in 1944, the company produced lindane until 1982. Until the early 50s only technical HCH are produced. Then the company began to separate lindane

#### <u> Aragón:</u>

Industrias Químicas del Noroeste (INQUINOSA), in Sabiñánigo (Huesca) founded in 1975. Its production finished in 1989 (It was the last facility of lindane in Spain), but it kept its commercial activity, and it imported and packaged lindane until 1991.

#### Galicia:

Laboratorios Zeltia, in O Porriño (Pontevedra) founded in 1939. The company produced lindane during 1947-1964. Since 1947 the company manufactured HCH and formulations in the 1950s began to separate from the rest of lindane isomers of HCH.

#### Cataluña:

Cruz Verde. In Barcelona. It produced lindano in 50s.

Fabricación Nacional de Colorantes y Explosivos SA founded in 1922. In 1953 manufactured different types of insecticides, including, lindano. Sociedad Electroquímica de Flix founded in 1897. It produced lindano in 1960.

#### Madrid:

Destilerías Químicas DIM SA founded in 1940. It produced lindano in 1963.

We would also appreciate any reference/web-link/contact person regarding any

(historic) production site in other EU Member state.

## 2. Are you aware of any lindane disposal, dumping or polluted sites in your country?

⊠Yes

□No

If "yes", please provide information on the site and its location and/or any reference/web-link/contact person regarding this information.

#### País Vasco:

Ebro Basin Organization reported in February of 2015 of existence of concentrations of HCH above quality standard at the station 0179 FQ (Zadorra/Vitoria-Trespuentes). The source of pollution is at municipal landfill (urban solid waste landfill).

Nervión River with HCH levels above the new Quality Standards (NCA-MA= 20 ng/l)

#### <u>Aragón:</u>

#### Sardas landfill:

HCH solid waste: 60.000 m<sup>3</sup>

HCH DNAPL: 30 m<sup>3</sup>

 Those waste are mixed with other kind of dangerous waste until sum 350,000 m<sup>3</sup>

#### Bailín landfill:

HCH solid waste: 65.000 t
 HCH liquid waste (DNAPL): 25 t
 Contaminated soils: 342.000 t

#### Castilla y León:

Borobia (Soria) in Gandalia Mine in Mount of public utility no 3 "Dehesa de la Hoya":

Report of the Ebro Basin Organization with date 16 of November of 2015 indicates that it have been detected traces of  $\beta$ -HCH although in much lower concentrations set out in the Directive 2006/118/CE.

Report of Service Environmental Prevention and Climate Change to date 16/05/2016 indicates that it have been detected  $\beta$ -HCH y  $\alpha$ -HCH in concentrations above the generic reference levels set out in RD 9/2005.

#### Galicia:

The soils in O Porriño (Torneiros area) where there were industries dedicated to lindane production, were included in the Plan of Contaminated Soils and the Operation Programme of the Xunta de Galicia. The first analyses (1998) showed contaminant values above the quality objectives, leading to the declaration of these soils as contaminated, by different regulations of the Xunta de Galicia. In this area, there are now various installations, subject to environmental authorisations: Syngenta Agro and Astra Zéneca Farmacéutica, which have piezometric networks showing high levels of lindane in the waters.

#### <u>Navarra:</u>

In Navarre about 40 years ago there were discharges of lindane, one in Iguzquiza and another in Viana.

In 2016 it has started an investigation file in order to assess the current status. This review is not motivated by any health or environmental problems requiring urgent action. It is only to assess the current state of the affected areas.

The results are not available yet

3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	⊠Yes □No
--	----------

If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) on this issue?? (in your county or at international level)

#### País Vasco:

The historical waste of HCH produced by the factories had been illegally dumped. With considerable help from the Cohesion Funds, the Basque Government undertook the cleaning of the numerous soil industrial sites contaminated by lindane. The solution chosen to confine soil contaminated with lindane, the waste from the treatment station (BCD process), based on the available technology and size of operations, included the construction of an isolation contaminated zone with a security cell on Mount Argalario (412,000 m³) in Baracaldo. It was constructed according to international measures required for technical inspection, health and safety. The cell was filled and finally sealed in 2003. Under this project proceeded sanitation of 23 sites.

#### Aragón:

Inquinosa factory. Characterization of contaminated infrastructure and soil. It is a previous step to to the drafting of the project of the demolition. (Acting area 2 ha).

#### Galicia:

The declaration of the soil as contaminated led to different activities aiming at controlling or reducing the risk to the human health and the ecosystems:

- The zones with higher concentrations were fenced, the water supply wells were closed and the agricultural use of the area was restricted.
- The main focus was confined by means of a mixture of cement and bentonite; inside this cell were deposited the soils with lindane concentrations between 2-5 mg/kg. The soils with concentrations above 5 mg/kg were transferred to a security deposit.
- Clinical analysis were performed, intended to determine a posible afectation to the population, and it was concluded that there was no relevant affectation, and that the risk for the population was slight.
- On the industrial site in which the enterprises Zéneca Farma (Astra Zéneca) and Zéneca Agro (Syngenta Agro) were located, sealing with geoxtile grids were performed, to prevent infiltration of rainwater, and piezometric controls were installed.
- The North Basin Organization installed a piezometric network and periodically controls, starting in july 2001.

## 4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?

⊠Yes

□No

If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) regarding de-pollution of environmental compartments (soil and surface/ground water/sediments) contaminated with lindane?

### Aragón:

Aragón has created the Management Unit to Comprehensive De-pollution of Lindane as a specialized technical center. It is structured in several technical areas that deal with the management, monitoring, control, research and communication of that decontamination. (http://www.aragon.es/lindano)

### The actions taken are:

#### Sardas landfill

- Waterproofed surface of the landfill in 1994.
- o Hydrogeological monitoring of the landfill.
- o 100 sounding.
- o Boom control.
- Pumping liquid waste of HCH (DNAPL, dense non-aqueous phase liquid).
- o Modeling aquifer.

### Bailín landfill

- o Waste transfer from the old landfill to a security cell in 1994.
- Hydrogeological monitoring of the landfill.
- o 150 sounding.
- o Boom control.
- o Pumping liquid waste of HCH (DNAPL).
- o Modeling aquifer.

### Other horizontal actions

- Maintenance of sewage plants Sardas, Bailin Baillín 1 and 2.
- Analytical in sewages plants and sounding.
- Monitoring and analytical of Gállego river to collect water for drinking.
- Monitoring of integrated environmental authorization of the new Bailín landfill.
- Disposal of hazardous waste.

### The actions planned are:

### Inquinosa factory:

 Characterization of contaminated infrastructure and soil. It is a previous step to to the drafting of the project of the demolition. (Acting area 2 ha).

### Sardas landfill:

- o Hydrogeological monitoring of the landfill. 6 new sounding in 2016.
- o Injection tests surfactants.

### Bailín landfill:

- o Field test. Bioremediation of soils.
- New laboratory of analysis for HCH.
- Scientific test of LIFE-DISCOVERED. In situ chemical oxidation of HCH waste in the aquifer.
- Hydrogeological monitoring of the landfill. 6 new sounding in 2016.

- Field test of in situ chemical oxidation plus surfactants to de-pollute of the aquifer.
- o Installation of 4 additional automatic samplers in the river Gállego.

### Galicia:

- Astra Zéneca Farmacéutica removed contaminated soil to a security deposit, performed impermeabilization of surfaces, changed the sewerage and drainage networks, and performed a bioremediation with a poplar plantation (*Populus sp.*), which favours degradation of HCH compounds.

### 

If "yes", can you briefly explain your experience or provide information (also references/web-links/ contact\_persons) on lindane treatment methods and residues?

### País Vasco:

Treatment plant to eliminate or irreversibly transform the pure lindane by a chemical treatment called BCD (Base Catalysed Dechlorination process), which destroys the HCH at a temperature of 150° by means of a chemical reaction that converts it to sodium chloride (common salt), trichlorobenzene (TCB) and water. The research allowed to maximise the efficiency of the reaction to attain a conversion rate of 99.9995% on a throughput of one tonne per hour. At Barakaldo, in its two years of operation before its decommissioning in 2001, the station eliminated 3200 tonnes of pure HCH. This process permitted the recycling of 1074 tonnes of TCB, distilled and commercialized as a primary material for the chemical industry without the difficulties associated to other methods of production. Likewise, the salt resulting from the conversion of the HCH was purified and used for the production of brine. The residue was transferred to the isolation zones.

### Aragón:

Project Life-Discovered: is a demonstration project co-funded by the European Union and coordinated by the Government of Aragón, for the remediation of contaminated soils in the area of Sabiñánigo (Huesca) by means of a chemical oxidation technique. One of the main tasks of the project is to demonstrate that the high rates of pollutant destruction achieved in the lab may be also achieved on the field. For that purpose, it will be developed an ISCO pilot test to mobilize and oxidize the pollutants (DNAPL) that could not be pumped out and are still trapped in the fractures. The aim is to reduce the existing pollution load in the aquifer and to turn it into less harmful or innocuous compounds. http://en.lifediscovered.es/

6. Regarding information to citizens, is there any	⊠Yes	□No
official website providing information or campaign on	M 163	
hazardous chemicals (and specifically on lindane) in		
your country?		

In case of "yes", please provide the web-link:				
http://www.magrama.gob.es/es/calidad-y-evaluacion- ambiental/temas/productos-quimicos/				
http://www.magrama.gob.es/es/calidad-y-eambiental/temas/productos-quimicos/conta				
In case the information is not in English, ple on hazardous chemicals is provided:	ease specify	what kind of information		
Health and/or environmental risks	⊠Yes	□No		
Polluted sites	⊠Yes	□No		
Exposure through articles and/or food and/o sources	or other ⊠Yes	□No		
Environmental and human monitoring data:	□Yes	□No		
Recommendations to reduce exposure	□Yes	□No		
Regulations and policies	⊠Yes	□No		
Links to other websites	⊠Yes	□No		
In case of "No", please indicate the reasons, if any				

### **Basque Country**

Nombre de contacto: Mª José Betanzos Ibarra			
Correo electrónico: mj-betanzos@euskadi.eus			
Institución/Organización: Dirección de Administración Am	biental		
País: Basque Country, Spain			
1. Are you aware of any (historic) lindane production site in your country? / ¿Sabe de la existencia de alguna planta (histórica) de producción de lindano en su país?	□Sí	□No	
En caso afirmativo, aporte información sobre las plantas, lugares de contacto / enlace web / referencia con respecto a dicha inform	•	er persona	
En la CAPV existieron dos plantas productoras de lindano. Durante el período comprendido entre el año 1.947 y 1.987 la fábrica de Bilbao-Chemicals, situada en Barakaldo, produjo unas 75.000 toneladas de residuos de HCH.			
En paralelo, la empresa Nexana Industrias Químicas situada en Erandio, produjo lindano durante el período comprendido entre 1952 y 1982, estimándose en 7.000 toneladas los residuos de HCH generados.			
También agradeceríamos cualquier persona de contacto / enlace a una web / referencia con respecto a alguna planta (histórica) de producción de lindano en otro estado miembro de la UE.			
2. Are you aware of any lindane disposal, dumping or polluted sites in your country? / ¿Sabe de la existencia de algún punto o lugar de eliminación, vertido de lindano, o que esté contaminado con el mismo, en su país?	□Sí	□No	
En caso afirmativo, aporte información sobre el lugar y su ubicación o cualquier persona de contacto / enlace web / referencia con respecto a dicha información.			
Consecuencia de la actividad productora del pesticida lindano en la CAPV y de la inadecuada gestión de los residuos producidos por dicha actividad, durante las últimas décadas del siglo XX se generaron en la CAPV numerosos emplazamientos altamente contaminados que representaban una clara amenaza tanto para la salud pública como para el medio ambiente, suponiendo además un freno que impedía el desarrollo de las áreas en las que se encontraban ubicados. Como ya se ha indicado, en los años 90 se inventariaron del orden de 40 emplazamientos altamente contaminados.			

En relación con contaminación de aguas, en los últimos años se han identificado las siguientes afecciones a masas de agua en el ámbito del País Vasco:

Embalse Loiola (Bizkaia). En el mes de julio de 2008 se detectaron niveles anómalos en HCH en el embalse Loiola (Bizkaia), por lo que fue cerrado al abastecimiento de forma inmediata hasta que se pudiera garantizar la calidad del agua con la máxima seguridad sanitaria para la población. A través de una comisión interinstitucional se realizaron diferentes estudios para determinar el origen de la contaminación y eliminar los correspondientes focos, incluyendo

trabajos relativos a la determinación de las áreas de recarga del manantial y su funcionamiento hidrogeológico, ensayos con trazadores y reconocimientos espeleológicos, inventarios de escombreras y otros focos de contaminación, numerosos sondeos y catas, y analíticas en distintas matrices con el fin de identificar el foco de la contaminación y las circunstancias que pudieran favorecer la presencia del contaminante en el embalse; y se actuó en la eliminación de antiguos vertederos.

En marzo de 2014, la Comisión Europea lanza el proyecto piloto 6235/14/ENVI, sobre posible contaminación por lindano de las aguas de la presa de Loiola (Bizkaia). En el marco del citado expediente, tanto URA-Agencia Vasca del Agua, ente público de derecho privado vinculado al Departamento de Medio Ambiente y Política Territorial, como el Departamento de Salud del Gobierno Vasco remitieron un exhaustivo informe acompañado de documentación complementaria en un CD para dar contestación a este asunto. En enero de 2016, la Comisión Europea introduce en la aplicación informática de Proyecto Piloto, la indicación de que este expediente aparece como cerrado.

En la actualidad el embalse está sometido a controles periódicos de la calidad del agua y del sedimento, cumpliendo con los requisitos de estado químico de la Directiva 2000/60/CE del Parlamento Europeo y del Consejo, de 23 de octubre de 2000, por la que se establece un marco comunitario de actuación en el ámbito de la política de aguas (DMA).

Río Zadorra (Alava). En febrero de 2015 la Confederación Hidrográfica del Ebro informa a la Agencia Vasca del Agua de la existencia de concentraciones de HCH superiores a la Norma de Calidad Ambiental en la estación 0179-FQ (Zadorra / Vitoria –Trespuentes). A raíz de esta situación URA ejecutó un control de investigación en el entorno, que determinó el origen en el vertedero municipal de residuos sólidos urbanos. En este marco, se ha instado al titular de la citada infraestructura a presentar el plan de acción que permita corregir esta situación, el cual se está elaborando en estos momentos.

Masa de agua de transición Nerbioi (Bizkaia). El Plan Hidrológico de la Demarcación Hidrográfica del Cantábrico Oriental¹ determina la existencia de mal estado químico en dos masas de aguas de transición (Nerbioi interior y Nerbioi exterior) y en diferentes tramos de sus tributarios, con superaciones locales de las nuevas normas de calidad establecidas para HCH (NCA-MA= 20 ng/l²). Esta situación de mal estado no fue evaluada de la misma forma en el pasado puesto que las normas de calidad anteriores eran menos exigentes (100 ng/l³). En estas masas de agua el Plan Hidrológico ha planteado el desarrollo de un plan de actuación para la consecución del buen estado químico, así como una prórroga de cumplimiento de objetivo hasta el 2027.

Real Decreto 60/2011, de 21 de enero, sobre las normas de calidad ambiental en el ámbito de la política de aguas, derogado por el Real Decreto 817/2015, de 11 de septiembre, por el que se establecen los criterios de seguimiento y evaluación del estado de las aguas superficiales y las normas de calidad ambiental.

Orden de 12 de noviembre de 1987 sobre normas de emisión, objetivos de calidad y métodos de medición de referencia relativos a determinadas sustancias nocivas o peligrosas contenidas en los vertidos de aguas residuales.

109

Real Decreto 1/2016, de 8 de enero, por el que se aprueba la revisión de los Planes Hidrológicos de las demarcaciones hidrográficas del Cantábrico Occidental, Guadalquivir, Ceuta, Melilla, Segura y Júcar, y de la parte española de las demarcaciones hidrográficas del Cantábrico Oriental, Miño-Sil, Duero, Tajo, Guadiana y Ebro

3. Do you have experience on technologies or best	П№
practices regarding the dismantling and cleaning-up of	
polluted production sites? / ¿Tiene usted experiencia en	
tecnologías o mejoras prácticas relativas al	
desmantelamiento y limpieza de plantas de producción	
contaminadas? (contaminadas no solo con lindano)	

En caso afirmativo, ¿podría explicar brevemente su experiencia o aportar información (así como personas de contacto / enlaces web / referencias) sobre dicho tema? (Tanto en su país como a nivel internacional)

Las dos instalaciones productoras de lindano fueron demolidas de manera selectiva. Los residuos procedentes de dicha demolición que estaban contaminados por HCH se almacenaron en un depósito construido para el confinamiento de tierras contaminadas por HCH (la celda de seguridad de Argalario). Igualmente se hizo con los suelos contaminados sobre los que se ubicaban ambas instalaciones.

4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment? /	□Sí	□No
¿Tiene experiencia en la descontaminación de terrenos o compartimentos acuáticos contaminados con lindano?		

En caso afirmativo, ¿podría explicar brevemente su experiencia o aportar información (así como personas de contacto / enlaces web / referencias) relativas a la descontaminación de compartimentos medioambientales (terrenos y superficie / aguas subterráneas (capas freáticas) / sedimentos) contaminados con lindano?

En el ámbito de la CAPV se llevó a cabo una labor de identificación de posibles emplazamientos contaminados por residuos de HCH, y que se correspondían con las parcelas en las que desarrollaban su actividad las empresas antes indicadas y con emplazamientos en los que se había procedido al depósito incontrolado de los residuos de HCH. De esta forma se identificaron 40 emplazamientos.

Debido a las características de los suelos contaminados por residuos de HCH, y tras un análisis de alternativas, la única solución sostenible identificada para su tratamiento, fue la de excavación y depósito en una infraestructura de seguridad construida para tal fin, infraestructura que debería ser sometida durante su construcción y tras la misma a intensos controles constructivos, ambientales y de seguridad.

Así los suelos contaminados procedentes de los 40 emplazamientos que habían sido previamente identificados fueron confinados en dos depósitos de seguridad: la celda de seguridad de Loiu construida en dicho término municipal, y la celda de seguridad de Argalario construida en el término municipal de Barakaldo.

Para la recuperación de cada uno de estos 40 emplazamientos contaminados se definió un protocolo de saneamiento específico al igual que para el transporte de las tierras contaminadas hasta los depósitos de seguridad.

El agua contaminada identificada en cada uno de los emplazamientos sobre los que se actuó, fue trasladada a las dos plantas de tratamiento de lixiviados de HCH construidas junto a los depósitos de seguridad. En función de la concentración que presentaban en HCH, estas aguas contaminadas eran tratadas a través de un proceso de osmosis inversa o a través de filtros de carbón activo.

En los emplazamientos afectados por este contaminante identificados posteriormente a la clausura de las celdas de seguridad, los suelos contaminados han sido excavados

para ser posteriormente gestionados por gestor autorizado para su eliminación en vertedero.

# 5. Do you have any experience on lindane waste treatment? / ¿Tiene alguna experiencia en el tratamiento de residuos de lindano?

□Sí □No

En caso afirmativo, ¿podría explicar brevemente su experiencia o aportar información (así como personas de contacto / enlaces web / referencias) sobre los métodos y residuos del tratamiento del lindano?

Los residuos de HCH puros abandonados en las propias instalaciones de las plantas productoras, fueron tratados a través del proceso BCD (Based Catalyzed Decomposition), tecnología química que estaba siendo desarrollada por la EPA (Agencia de Medio Ambiente del Gobierno de los Estados Unidos). Su tratamiento se llevó a cabo en una planta construida a tal efecto en los terrenos en los que desarrolló su actividad la mercantil Bilbao-Chemicals, una de las actividades productoras de estos residuos.

6. Regarding information to citizens, is there any official website providing information or campaign on hazardous chemicals (and specifically on lindane) in your country? / Con respecto a la información a los ciudadanos, ¿existe alguna web oficial en la que se ofrezca información o se presente una campaña sobre sustancias químicas peligrosas (y, más concretamente, sobre el lindano) en su país?

□Sí	□No
-----	-----

En caso afirmativo, indique por favor el enlace web correspondiente:

Plan de suelos contaminados del País Vasco 2007-2012

http://www.ingurumena.ejgv.euskadi.eus/r49-

<u>orokorra/es/contenidos/plan/suelos contaminados/es plan/adjuntos/plan suelos contaminados.pdf</u>

Información sobre la construcción de los depósitos de seguridad puede consultarse a través de la siguiente publicación:

http://www.ihobe.eus/Publicaciones/Ficha.aspx?IdMenu=750e07f4-11a4-40da-840c-0590b91bc032&Cod=ef1f5a8a-683d-4a18-84c5-84aa9cf5fe3d&Idioma=es-ES&IdGrupo=PUB&IdAno=2002&IdTitulo=001

Información sobre la evolución de las concentraciones de HCH en el embalse Loiola: <a href="http://www.uragentzia.euskadi.eus/informe">http://www.uragentzia.euskadi.eus/informe</a> estudio/evolucion-de-las-concentraciones-de-hexaclorociclohexano-en-el-embalse-oiola-valle-de-trapaga-trapagaran/u81-0003771/es/

Información sobre evolución del estado químico en el río Zadorra (resultados generales de la red de seguimiento del País Vasco):

http://www.uragentzia.euskadi.eus/informacion/ultimos-informes/u81-0003342/es/

Plan Hidrológico de la Demarcación Hidrográfica del Cantábrico Oriental:

http://www.uragentzia.euskadi.eus/informacion/plan-hidrologico-de-la-demarcacion-hidrografica-del-cantabrico-oriental-2015-2021/u81-0003333/es/

Si la información no estuviera en inglés, rogamos especifique qué tipo de información sobre sustancias químicas peligrosas se está facilitando:

Riesgos para la salud o medioambientales	5	□Sí	□No	
Lugares contaminados		□Sí	□No	
Exposición por artículos, comida y otras fuentes	□Sí	□No		
Datos de control medioambiental y humar	no: 🗆Sí	□No		
Recomendaciones para reducir la exposicio	ón	□Sí	□No	
Reglamentos y políticas	□Sí	□No		
Enlaces a otras webs	□Sí	□No		
En caso negativo, indique los motivos, si es que los hubiera				

### **ASDEN**

Contact name: Javier			
e-mail: asden.soria@gmail.com			
Institution/Organization: Asociación ASDEN-Ecologistas en Acción de Soria			
Country: SPAIN			
1. Are you aware of any (historic) lindane production site in your country?			
□Yes xNo			
If "yes", please provide information on the plants, locations and/or any reference/web-link/contact person regarding this information.			
Mina Gandalia (Borobia, Soria, Castilla y León, Spain)			
We would also appreciate any reference/web-link/contact person regarding any (historic) production site in other EU Member state			
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?   xYes □No			
If "yes", please provide information on the site and its location and/or any reference/web-link/contact person regarding this information.			
Mina Gandalia (Borobia, Soria, Castilla y León, Spain) UTM etrs89 30T Coord. X:591.997 Coord. Y: 4.615.640.			
$\underline{https://www.dropbox.com/sh/lm6t3zfqtliy51j/AACI3AoCMS3qwqYpI0795G4Ba?dl=0}$			
Cabria (Palencia, Castilla y León, España)			
Asociación ASDEN: asdensoria@gmail.com			
. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)  □Yes xNo			
If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) on this issue?? (in your county or at international level)			
4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?  □Yes xNo			
If "yes", can you briefly explain your experience or provide information (also			

references/web-links/contact persons) regarding de-pollution of environmental compartments (soil and surface/ground water/sediments) contaminated with lindane?			
5. Do	you have any experience on lindane was	ste treatm	ent?
□Yes	xNo		
	s", can you briefly explain your experience or nces/web-links/ contact persons) on lindane es?	•	•
provi	garding information to citizens, is there ding information or campaign on hazard fically on lindane) in your country?		
□Yes	□No		
In cas	e of "yes", please provide the web-link:		
In case the information is not in English, please specify what kind of information on hazardous chemicals is provided:			
-	Health and/or environmental risks	□Yes	□No
-	Polluted sites	□Yes	□No
-	Exposure through articles and/or food and/o sources	or other □Yes	□No
-	Environmental and human monitoring data:	□Yes	□No
-	Recommendations to reduce exposure	□Yes	□No
-	Regulations and policies	□Yes	□No
-	Links to other websites	□Yes	□No
In case of "No", please indicate the reasons, if any			



addition out.

Brussels, 29 September 2016

Dear Sir, dear Madam,

The European Parliament's Policy Department for Citizens' Rights and Constitutional Affairs at the request of the European Parliament's Committee on Petitions (PETI) has invited ERA-Consult to carry out an in-depth analysis on "Lindane (Persistant organic Pollutant) in the EU".

In particular, the study should cover the mapping of Lindane in the EU member States, soil and groundwater de-pollution possibilities and best practices in de-polluting among the Member States affected by this problem. The study was launched in July 2016 and should be ready in November of 2016.

In order to ensure that we have access to all relevant and updated information, we would be very grateful if you could give input to this brief questionnaire. We could also arrange a call in order to collect your feedback. Please feel free to pass this questionnaire on to any contact that you feel may wish to have input to this study.

Thank you in advance for your co-operation with this request, and we look forward to receiving your contribution. We will inform you on any potential publication.

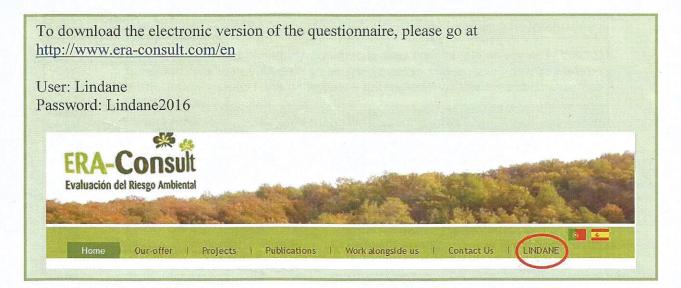
For any further information please contact with

Milagros Vega

vega@era-consult.com

Phone: (+34) 687 69 15 98

http://www.era-consult.comERA-Consult (Madrid, Spain)





## Study on "Lindane (Persistant Organic Pollutant) in the EU"

In order to compile information on lindane production and dumping sites in Europe, as well as best practices in de-pollution techniques, we would appreciate your contribution to the following questions.

Contact name: Stephan Kobinson		î		
e-mail: stephen, Tobinson RgTe Institution/Organization: Green Cross Swi	enco	oss,ch		
	120 la	in B		
Country: Switzerland				
1. Are you aware of any (historic) lindane production site in your country?	Yes	□No		
If "yes", please provide information on the plants, locations and/or link/contact person regarding this information.	any reference	ence/web-		
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	XYes	□No		
If "yes", please provide information on the site and its location and link/contact person regarding this information.	or any re	ference/web-		
3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	Yes	□No		
If "yes", can you briefly explain your experience or provide informative references/web-links/contact persons) on this issue?? (in your couldevel).		nternational		
4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?	□Yes	ĭNo		
If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) regarding de-pollution of environmental compartments (soil and surface/ground water/sediments) contaminated with lindane?				
5. Do you have any experience on lindane waste treatment?	□Yes	Ź₩0		
If "yes", can you briefly explain your experience or provide information (also references/web-links/ contact persons) on lindane treatment methods and residues?				
6. Regarding information to citizens, is there any official website providing information or campaign on hazardous chemicals (and specifically on lindane) in your country?	Wes	□No		
In case of "yes", please provide the web-link:	nin-cl	^		

## **Greenpeace Central and Eastern Europe**

Contact name: Gergely Simon				
e-mail: Email: gergely.simon@greenpeace.org Institution/Organization: Greenpeace Central and Eastern Europe (CEE) (Budapest Office)				
Country: Hungary				
1. Are you aware of any (historic) lindane production site in your country?	⊠Yes	□No		
If "yes", please provide information on the plants, locations and reference/web-link/contact person regarding this information.	d/or any			
Budapest Vegyi Müvek, in central Budapest.				
Story about this site: <a href="https://www.yahoo.com/news/cleanup-tasks-delayed-defunct-chemical-plant-hungary-085422335.html?ref=gs">http://greenpeace.blog.hu/2035.html?ref=gs</a> , <a href="http://greenpeace.blog.hu/2016/01/15/success">http://greenpeace.blog.hu/2016/01/15/success</a> all toxic waste removed from illato s rd site of former budapest chemical works				
We would also appreciate any reference/web-link/contact person regarding any (historic) production site in other EU Member state				
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	⊠Yes	□No		
If "yes", please provide information on the site and its location and/or any reference/web-link/contact person regarding this information.				
Lindane pollution is likely to be present at the above mentioned	l site.			
3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	□Yes	⊠No		
If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) on this issue?? (in your county or at international level)				

4. Do you have experience on de-pollut contaminated soils and/or aquatic com			□Yes	⊠No
If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) regarding de-pollution of environmental compartments (soil and surface/ground water/sediments) contaminated with lindane?				
5. Do you have any experience on linda treatment?	ne waste		□Yes	⊠No
If "yes", can you briefly explain your experie references/web-links/ contact persons) on li	•		•	
6. Regarding information to citizens, is website providing information or campa chemicals (and specifically on lindane)	aign on ha	zardous	⊠Yes	□No
In case of "yes", please provide the web-link:				
we at Greenpeace often inform the public: <a href="www.greenpeace.hu">www.greenpeace.hu</a> , greenpeace.blog.hu also a blog vegyi.blog.hu & some facebook groups				
In case the information is not in English, please specify what kind of information on hazardous chemicals is provided:				
Health and/or environmental risks	⊠Yes	□No		
Polluted sites	⊠Yes	□No		
Exposure through articles and/or food and/o sources	or other ⊠Yes	□No		
Environmental and human monitoring data:	⊠Yes	□No		
Recommendations to reduce exposure	⊠Yes	□No		
Regulations and policies	⊠Yes	□No		
Links to other websites	⊠Yes	□No		
In case of "No", please indicate the reasons	, if any			

## Martin Forter, Independent scientist for municipalities, residents and environmental organisations

Contact name: Martin Forter				
e-mail: martinforter@martinforter.ch				
Institution/Organization: Independent scientist for municand environmental organisations	cipalities, r	esidents		
Country: Switzerland (and France)				
1. Are you aware of any (historic) lindane production site in your country?	⊠Yes	□No		
If "yes", please provide information on the plants, locations and, reference/web-link/contact person regarding this information.	or any			
Ugine Kuhlmann, Huningue, France, produced until 1976				
Maag Dielsdorf, Switzerland (do not know end of production)				
We would also appreciate any reference/web-link/contact persor (historic) production site in other EU Member state.	n regarding	any		
Concerning Ugine Kuhlmann, Huningue:				
http://www.martinforter.ch/images/news/2015_11_07/Forter- Lindane_by_UgineKuhlmannn.pdf				
http://www.martinforter.ch/images/news/2013_09_25/08_19950600_Martin_Forter-Umweltnutzung.pdf				
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	⊠Yes	□No		
If "yes", please provide information on the site and its location and/or any reference/web-link/contact person regarding this information.				
List of sites in annexe (20151025 Sites of Lindan-producer Ugine Huningue, France.pdf)	e Kuhlmann	,		
3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	⊠Yes	□No		
Cleaning up the site of Bonfol (Switzerland), Hirschacker (Grenz Germany), Le Letten (Hagenthal-le-Bas, France) and Roemisloch Feldreben in Switzerland (Muttenz, Switzerland). See http://www	າ (Neuwiller	France),		
4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?	⊠Yes	□No		
If "yes", can you briefly explain your experience or provide infor references/web-links/contact persons) regarding de-pollution of compartments (soil and surface/ground water/sediments) conta	environmer	ntal		

lindane? Good and not good projects to clean up theese sites. I am involved as expert for municipalities, residents and environmental organisations				
5. Do you have any experience on linda treatment?	ne waste	e	⊠Yes	□No
If "yes", can you briefly explain your experience or provide information (also references/web-links/ contact_persons) on lindane treatment methods and residues?  It should be burned				
6. Regarding information to citizens, is there any official website providing information or campaign on hazardous chemicals (and specifically on lindane) in your country?   □No □No				
In case of "yes", please provide the web-link	<b>&lt;:</b>			
http://www.martinforter.ch				
In case the information is not in English, please specify what kind of information on hazardous chemicals is provided:				
Health and/or environmental risks ⊠Yes □No				
Polluted sites	⊠Yes	□No		
Exposure through articles and/or food and/or other sources $\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$				
Environmental and human monitoring data: ⊠Yes □No				
Recommendations to reduce exposure	□No			
Regulations and policies $\square$ Yes $\square$ No				
Links to other websites	⊠Yes	□No		
In case of "No", please indicate the reasons,	, if any			
	,			

# Study on "Lindane (Persistant Organic Pollutant) in the EU"

In order to compile information on lindane production and dumping sites in Europe, as well as best practices in de-pollution techniques, we would appreciate your contribution to the following questions.

Contact name: Matthijs Bouwknegt MSc				
e-mail: BKT@tauw.com				
Institution/Organization: Tauw bv				
Country: The Netherlands				
1. Are you aware of any (historic) lindane production site in your country?	⊠Yes	□No		
If "yes", please provide information on the plants, locations a reference/web-link/contact person regarding this information				
To my knowledge the most extensive overview available is the following of John Vijgen of the IHPA:	document pre	pared by		
http://www.ihpa.info/docs/library/reports/Lindane%20Main%20Report%20DEF20JAN06.pdf				
http://www.ihpa.info/docs/library/reports/Lindane%20AnnexesDEF20JAN06.pdf				
We would also appreciate any reference/web-link/contact person regarding any (historic) production site in other EU Member state.				
The annexes list details on other countries as well:				
http://www.ihpa.info/docs/library/reports/Lindane%20AnnexesDEF20JAN06.pdf				
2. Are you aware of any lindane disposal, dumping or polluted sites in your country?	⊠Yes	□No		
If "yes", please provide information on the site and its location reference/web-link/contact person regarding this information		ny		
See above documentation				

3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	⊠Yes	□No	

If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) on this issue?? (in your county or at international level)

Yes, see some selected references below:

### 1) Remediation & dismantling of a former Lindane production facility, The Netherlands

Investigation, planning, supervision of implementation; large-scale excavation, on-site application of contaminated soil, groundwater containment, construction.

Management and supervision of the demolition works and soil and groundwater remediation works were performed under environmental supervision of Tauw bv. Well considered planning and consultancy with all involved parties resulted in the timely completion of the works and start of the construction of the college buildings.

The project included the setting up of a remediation plan for the removal of HCH and chlorobenzene from a former industrial site, as well as the project management and supervision in the implementation phase. In the past, the site has been used for the production and storage of pesticides. For the redevelopment of the site for the establishment of a poly-technical college, the buildings, the production facilities had to be demolished and the site remediated.

The past handling of pesticides on site, mainly HCH, has lead to a severe contamination of the soil along the sewer track. The contaminants determined in the investigation reached a maximum depth of approx. 12 m -gl. On the entire site, the groundwater was found to be contaminated as well, with pollutants having reached a depth of some 10 m -gl. About 3 km downstream of the site, a contamination plume was detected at depths ranging from 20 to 35 m -gl.

In terms of the overall approach, it was decided to install a geo-hydrological containment system, so as to control the contamination and prevent further spreading. More specific measures were taken as regards the contamination plume and the site section designated for the construction of the school building. As the pesticide compounds bind strongly to dust, the formation of dust had to be prevented as much as possible. Tauw by drew up both the remediation planning and a demolition scenario, stating the requirements for a safe execution of the works.

This has been the first site in the Netherlands, where based on the assessment of humane toxicological hazards with the CSOIL-model, with approval of the Ministry of Environment, redevelopment of the site was allowed after a partial clean-up of the site. Remediation of the

subsoil by soil vapour extraction, up to the risk-limits for benzene and chlorinated benzenes is still in progress.

Duration was 1 year for actual soil remediation and installation of groundwater remediation system. The groundwater extraction system has been in operation since 1994. Contaminated groundwater was treated by a combination of biological and GAC treatment.

### 2) Dismantling and soil remediation confidential chemical industry

At a former industrial site of (confidential chemical industry) in the west of The Netherlands, several chemical factories have been active in production processes of which chlorinated compounds are used as a raw material.

After a long period of soil and groundwater investigations, the first remedial phase of the project consisted of the dismantling of the heavily contaminated aboveground production and storage facilities. Given the highly toxic nature of the contaminants, health and safety aspects were very stringent. As the pesticide compounds bind strongly to dust, the formation of dust had to be prevented as much as possible.

After the dismantling, the site could be distinguished into a vacant area and a built-on site section of equal size (8 to 10 ha). Soil investigations performed on the entire site since 1983 have shown that large parts of both the vacant and the built-on section are severely contaminated with chlorinated compounds, including HCH, PCB, chlorobenzenes and dioxins. Since remediation by means of excavating the soil was not feasible, it was decided that the groundwater be contained with the aim of preventing a vertical and horizontal dispersion of contaminants by way of the groundwater. To this end, the phreatic groundwater table had to be lowered by 2.5 m, to a depth greater than that of the hydraulic head in the aquifer.

It was found impossible to meet the objectives set in the built-on site section, due to the fact that the possibility of subsidences in the subsoil posed too much of a risk to the operation of the business. Therefore, the final version of the remediation plan provided for a sheet pile wall to be installed around the site as well as between the vacant and the built-on site sections. In the vacant site section, the groundwater table was lowered to 3.5 m -gl, while measures in the built-on section were limited to removing the surplus precipitation from the area within the sheet pile walls.

In-situ remediation eventually took place at the site consisting of soil vapour extraction, a flushing system, supplemented with natural biodegradation.

### -GENERAL STATEMENT-

Tauw has extensive of experience in the dismantling, decommissioning an clean-up (Remediation) of industrial sites.

Tauw offers a comprehensive range of services, products and expertise to national and multinational industries, public authorities and non-governmental organizations:

- · Contaminated land management, including soil and groundwater investigation and remediation
- · Water management and engineering, including rural development
- · Environmental management and engineering, including waste management

- Spatial planning and site development, including brownfield regeneration
- · Strategic consultancy and studies, including process and project management

Tauw has extensive experience in site-specific risk assessment and remediation technologies onsite, in-situ and off-site. Services are continuously improved through our innovation program. The long track record of Tauw's soil-related services include soil surveys, soil policy studies, risk assessment, remediation planning, design, licensing, health and safety, and soil quality management.

Tauw's soil department is an active partner in NICOLE (network for industrially contaminated land in Europe), ISO and CEN certification institutes and networks of branch organizations, export and governmental expertise platforms.

## 4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?

⊠Yes

□No

If "yes", can you briefly explain your experience or provide information (also references/web-links/contact persons) regarding de-pollution of environmental compartments (soil and surface/ground water/sediments) contaminated with lindane?

Yes, see some selected references below:

### 1) Bioremediation of HCH sites

In the past, soil and groundwater at a number of sites in the East Netherlands became contaminated with hexachlorocyclohexane (HCH). Up to that time, it was unknown whether HCH was biologically degradable. 'Pump-and-treat' was the only remediation option available. However, it has now been demonstrated (by a consortium of Tauw, TNO-MEP, Wageningen University,) under controlled conditions, that even the most recalcitrant HCH compound is biologically degradable, via sequential anaerobic-aerobic degradation.

A bio-screen was installed at the site, in which the anaerobic degradation of HCH was stimulated by the infiltration of an electron donor. The construction of the bio-screen coincided with the redevelopment of the site into a container terminal and both were constructed at the same time. Subsequent to this, infiltration with an electron donor was started and biological processes at the site were followed via extensive monitoring. This demonstrated that the HCH at the site is degraded biologically and that conversion can be stimulated by infiltrating methanol. The system constructed is robust and was not hampered by any blockages. HCH is being converted and the bio-screen is more cost effective in the long term than a traditional "Pump-and-Treat" system would be.

2) Technical review of the EU funded Life+ DISCOVERED Sabinanigo research project Tauw is contracted for technical review and knowledge dissemination of the EU funded Life+ DISCOVERED Sabinanigo research project. The project aims to demonstrate the effectiveness of ISCO for in situ treatment of HCH soil and groundwater contamination at the Sabinanigo site in Aragon Spain. An extensive field pilot project to demonstrate the technology is currently in execution.

## 3) Assessment of HCH landfill, soil and groundwater contamination at a confidential MNI Site

Remediation strategy development and technical assistance of local site management regarding the handling and control of landfilled pesticides residues (45.000 ton Hexachlorocyclohexane) and the contaminated surroundings of an industrial Lindane production site. Tauw assisted the management in review of investigation reports, landfill design, tendering procedures and proposal writing.

Furthermore Tauw technically advises on soil and groundwater treatment options. A literature study on soil and groundwater treatment options has been performed. Laboratory experiments were conducted to determine treatment possibilities for contaminated soil and groundwater. For soil treatment sediment classification and fractionation was assessed and for contaminated groundwater treatment the feasibility of biological and chemical reduction with zero valent iron was investigated. Zero valent iron reduction proved very effective.

## 4) Volgermeerpolder, The Netherlands : remediation of a pesticide landfill and restoration of a natural reserve

In the 19th and 20th century peat was an important fuel in the Netherlands. In the north of Amsterdam peat layers with a thickness of up to 8 meter were excavated from the soil. In the Volgermeerpolder 100 ha wetland remaining after this extraction was used as a chemical and domestic waste dump for the municipality of Amsterdam until 1980. Residues from chlorinated pesticide production such as HCH were also deposited in the Volgermeerpolder, which resulted in contamination of the surrounding waterways with dioxins. Groundwater on the site is severely contaminated with aromatic and chlorinated compounds, mainly benzene and monochlorobenzene, both biodegradation products of the pesticides. However, the residual peat in the subsurface has limited migration of the contamination, resulting in a fragile but stable situation without off-site migration of contaminants.

A large scale remediation project for this area was initiated in 2003. From the beginning of the project planning it was clear that a remediation of the site by removal of the waste would not be feasible. A remediation concept was developed centred on the reclamation of the area as a constructed wetland with bog development. The waste deposit will be isolated using a low permeable layer (PE-liner). This cover layer will prevent infiltration of rain water, and reduce contaminant flux into the surrounding subsurface. The system will be constructed on top of this cover layer (see Figure 9), consisting of constructed wetlands controlled by a water management system. The aim is for gradual development of a bog in the area. A wider sustainability benefit of this bog development is the creation of a 100 ha carbon sink. The area will also be opened for recreational purposes, and will provide valuable habitat area.

5) Removal of a landfill containing chemical wastes (HCH) in The Netherlands
Tauw was responsible for planning, consultations with the authority in charge and other parties
concerned, environmental supervision, project management. Key words: safety measures,
excavation in peat/clay, dioxins.

In the sixties, a small lake near 'the canal' had been filled with soil, construction and demolition wastes and environmentally hazardous wastes, such as barrels containing industrial chemical waste products, among which dioxins and other organo-chlorinated compounds. The entire preparation and execution of the remediation were conducted by Tauw. The execution (including preparations) took 1.5 years.

As on waste dumps the contents of the barrels cannot be precisely determined in advance, the works were classified under the highest safety class (3T). In order to prevent risks for the surrounding area, dust measurements were carried out.

The excavated barrels were reduced in a closed processing unit on the site, and repacked in PE-barrels. Next, the repacked barrels were transported to a waste combustion installation. The other wastes were disposed of at a controlled landfill. The disposal/treatment at the controlled landfill was also supervised by Tauw.

At all times liquid-tight overalls and breath covers were used during the works. Given the specific risks associated to the handling of the barrels and dioxins, the works were under stringent management and supervision by Tauw.

In the course of the 60ies, a pond situated along the 'canal' was filled up with soil material and used as a dump for construction and demolition waste, and for barrels containing hazardous materials. The hazardous waste consisted of production residues of a chemicals manufacturing company, including highly toxic substances such as dioxin and other organochloro compounds. The resulting contamination was completely excavated and removed from the site

With the activities performed by Tauw falling under the highest safety class (i.e. 3T), the most stringent precautions had to be taken. Continuous dust measurements were carried out in order to prevent possible damages to the environment. The dug-up barrels were shredded in a closed processing unit installed on site, following which the contaminated material was repacked in PEdrums. These drums were then transported to the waste processing plant. The other waste materials were taken to the X landfill site, a part of which is specialized in landfilling such types of material. The processing of the material there was supervised by Tauw as well.

# 5. Do you have any experience on lindane waste treatment? □Yes ⊠No

If "yes", can you briefly explain your experience or provide information (also references/web-links/ contact\_persons) on lindane treatment methods and residues?

Tauw does not process pure product chemical waste, but we do have contacts and sometimes collaboration with the chemical waste treatment industry

officia hazaro	arding information to citizens, is there any I website providing information or campaign on lous chemicals (and specifically on lindane) in ountry?	⊠Yes	□No
	of "yes", please provide the web-link:		
-	Not specifically to Lindane, but to hazardous chemicals, yes:		
http://	www.rivm.nl/en/		
https:/	/www.government.nl/topics/hazardous-substances		
https:/	/www.government.nl/ministries/ministry-of-infrastruct	ture-an	d-the-
<u>enviror</u>	<u>iment</u>		
on haz	the information is not in English, please specify what ardous chemicals is provided:	kind of	information
-	Health and/or environmental risks ⊠Yes	s [	∃No
<u>http://</u>	www.rivm.nl/en/Topics/C/Consumer exposure to che	emical s	<u>substances</u>
	Polluted sites	□Ne	0
ncp.//			h
-	Government registry of contaminated sites (Dutch): <a href="http://bod/butch">http://bod/butch</a> : <a href="https://bod/butch">http://bod/butch</a> : <a href="https://bod/butch">http://bod/butch</a> : <a href="https://bod/butch">https://bod/butch</a> : <a href="https://bod/butch">h</a>		
https:/	/english.nvwa.nl/		
	www.rivm.nl/en/Topics/C/Consumer_exposure_to_che	emical s	substances
-	Environmental and human monitoring data: ⊠Ye		□No
-	Environmental monitoring is carried out extensively, for example	in our riv	ers (Dutch)
http://	www.clo.nl/nieuws/krw-beoordeling-waterkwaliteit-geo	<u>actualis</u>	<u>eerd-2015</u>
-	For HCH, google for example "waterkwaliteitsrapportage HCH"		
-	Examples on how to deal with the public on potential human hea	lth hazar	d (Dutch)
	www.rwsleefomgeving.nl/onderwerpen/bodem- rond/bodemconvenant/spoedlocaties/voorbeeldmateri	aal/	

<ul> <li>Human monitoring data are generally not publicly available but you can find evidence (a reference is made to) it is performed through media, e.g. google when there is a pollution scandal with potential human health risks</li> </ul>				
- Recommendations to reduce exposure	⊠Yes	□No		
http://www.rivm.nl/en/Topics/C/Consumer exposure	to chemi	<u>cal substances</u>		
- Regulations and policies	⊠Yes	□No		
http://rwsenvironment.eu/subjects/soil/legislation-ar	ıd/			
http://rwsenvironment.eu/subjects/environmental/				
All Dutch laws: http://wetten.overheid.nl/zoeken				
- Links to other websites	⊠Yes	□No		
https://www.overheid.nl/english				
http://www.ihpa.info/				
In case of "No", please indicate the reasons, if any				

### **UFZ**

Contact name: Dr. Hans H. Richnow e-mail: hans.richnow@ufz.de Institution/Organization: Department of Isotope Biogeochemistry Helmholtz Centre for Environmental Research - UFZ Permoserstraße 15, 04318 Leipzig **Country: Germany** 1. Are you aware of any (historic) lindane production ⊠Yes □No site in your country? If "yes", please provide information on the plants, locations and/or any reference/web-link/contact person regarding this information. Federal state of Sachsen-Anhalt Represented by: Landesanstalt für Altlastenfreistellung des Landes Sachsen-Anhalt -LAF Adresse: Maxim-Gorki-Straße 10, 39108 Magdeburg Telefon: 0391 744400 http://www.laf-lsa.de/ Dr. J. Stadelmanm (head of the LAGF) We would also appreciate any reference/web-link/contact person regarding any (historic) production site in other EU Member state..... 2. Are you aware of any lindane disposal, dumping or ⊠Yes □No polluted sites in your country? If "yes", please provide information on the site and its location and/or any reference/web-link/contact person regarding this information. Bitterfeld: Dumpsite "Antonie" in Sachsen Anhalt (LAF see Address above) Major producers are listed below: Böhringer Ingelheim, Hamburg Moorfleet, Ingelheim) BASF (Ludwigshafen) VEB Fahlberg List (Magdeburg, LAF see address above, https://de.wikipedia.org/wiki/Fahlberg-List) Merck (Darmstadt) VEB Berlin Chemie (http://arche-foto.com/berlinchemie.html)

VEB Fettchemie Karls-Marx Stadt (Federal State of Sachsen, Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, www.smul.sachsen.de/lfulg) Chemiekombinat Bitterfeld (see LAF above) Sonderabfalldeponie Malsch, (Malsch, north of Heidelberg, http://www.sad-bw.de/historie_M.html)				
3. Do you have experience on technologies or best practices regarding the dismantling and cleaning-up of polluted production sites? (not only polluted with lindane)	□Yes	⊠No		
If "yes", can you briefly explain your experience or provide in references/web-links/contact persons) on this issue?? (in you international level)		•		
4. Do you have experience on de-pollution of lindane contaminated soils and/or aquatic compartment?	⊠Yes	□No		
If "yes", can you briefly explain your experience or provide in references/web-links/contact persons) regarding de-pollution compartments (soil and surface/ground water/sediments) collindane?  Monitoring of Natural attenuation processes i sediment and aquatic system using stable is enantiomers  Biodegradation of HCH  Analysing the fate of HCH in the environment	of enviror ntaminate n aquifer otopes ar	nmental d with rs, soils,		
5. Do you have any experience on lindane waste treatment?	□Yes	⊠No		
If "yes", can you briefly explain your experience or provide in references/web-links/ contact_persons) on lindane treatment residues?		•		
6. Regarding information to citizens, is there any official website providing information or campaign on hazardous chemicals (and specifically on lindane) in your country?	⊠Yes	□No		
In case of "yes", please provide the web-link:				
The information of HCH contamination is in principle available web site and documents which can be found in the web.	e on many	different		
Not specific web sites are available summarising all informati	on on HCF	ł.		
In case the information is not in English, please specify what on hazardous chemicals is provided:	kind of inf	formation		
Health and/or environmental risks ⊠Yes □No				

Polluted sites	⊠Yes	□No		
Exposure through articles and/or food and/o sources	or other ⊠Yes	□No		
Environmental and human monitoring data:	⊠Yes	□No		
Recommendations to reduce exposure	⊠Yes	□No		
Regulations and policies	⊠Yes	□No		
Links to other websites	⊠Yes	□No		
In case of "No", please indicate the reasons, if any				

CAT: QA-05-16-021-EN-C (paper CAT: QA-05-16-021-EN-N (pdf)

### **DIRECTORATE-GENERAL FOR INTERNAL POLICIES**

# POLICY DEPARTMENT CITIZENS' RIGHTS AND CONSTITUTIONAL AFFAIRS

### Role

Policy departments are research units that provide specialised advice to committees, inter-parliamentary delegations and other parliamentary bodies.

### **Policy Areas**

- Constitutional Affairs
- Justice, Freedom and Security
- Gender Equality
- Legal and Parliamentary Affairs
- Petitions

### **Documents**

Visit the European Parliament website:

http://www.europarl.europa.eu/supporting-analyses

PHOTO CREDIT: iStock International Inc



ISBN 978-92-846-0329-9 (paper) ISBN 978-92-846-0328-2 (pdf)

doi: 10.2861/985104 (paper) doi: 10.2861/167592 (pdf)

