# Assessment of the socio-economic impact of the project actions on the local economy and population

## Hg-rid-LIFE
## Mercury Decontamination of Dental Care facilities

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## SUMMARY

This report presents the assessment of socio-economic impacts of the mercury abatement measures adapted in the Hg-rid-LIFE project on mercury decontamination of dental care facilities. The two abatement measures are decontamination of pipes, and the use of amalgam separators. The aim of the measures is to reduce the mercury discharge to the environment through the facilities wastewater.

Based on decontamination of 68 facilities within Sweden, we have estimated the benefits and costs for an average decontamination as well as for all the performed decontaminations within the project. An average decontamination generates a net benefit for society of 5.8 thousand Euro, with a benefit-to-cost ratio of 2.4 (however, with a wide range of -9.4 to 200 thousand Euro in net benefit/decontamination, depending on amount of mercury removed and valuation of effects). All 68 decontaminations performed within the project generated net benefit of 390 thousand Euro, with the benefit-to-cost ratio of 2.1 (with a range of -350 to 1 400 thousand Euro, depending on the monetary value set on mercury impacts).

For amalgam separators the analysis has been conducted per separator, indicating a benefit-to-cost ratio of 2.7 and a net benefit to society of 660 Euro (a range of -400 to 2080 Euro, depending on the monetary value of mercury).

A comparison between these two abatement measures, made for a 10-year period, indicates that amalgam separator results in a higher benefit-to-cost ratio of 2.8 compared to 2.4 for an average decontamination. Decontamination can be considered as an important complimentary measure to remove mercury from dental facilities that cannot be captured by amalgam separators – a mandatory abatement measure in the EU from January 1st, 2019.

Due to the high variation in the results, depending on both the amounts of removed mercury and the uncertainty of the monetary valuation of mercury, we see a need for more studies, especially on decontamination that seems to be an under-researched area compared to amalgam separators. This to verify the main findings from our study.

On an European level, building an efficient system for mercury waste handling and final disposal, which is needed for the dental clinics to comply with EU's recently implemented regulation on the mandatory use of amalgam separators, would not only decrease mercury discharge but also provide job opportunities enhancing the local and regional market.

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# 1. Introduction and background

In this report we present the results of the assessment of the socio-economic impact of actions within the Hg-rid-LIFE project *Mercury Decontamination of Dental Care facilities*. This LIFE project aims to reduce discharge of mercury (Hg) from dental clinics in Sweden, which is done by decontamination of selected dental facilities, information dissemination, and training[1] on maintenance routines for reducing water emissions of mercury from amalgam separators and handling of amalgam waste. The project's different objectives and tasks are further explained in the project's Final Report[2]. The evaluation of the project's aim on information and training, including increased knowledge and know-how on how to mitigate mercury leakage from dental facilities, is presented in the report "C1.5.1 Final Results, Conclusions and Recommendations". Hence, this evaluation is not included in this report.

The project was carried out between 01/09/2016 – 31/08/2019, by Praktikertjänst AB (PTJ), Sweden Recycling AB (SRAB) and the Swedish Environmental Research Institute (IVL), with financing via the EU LIFE Program - HG-RID-LIFE LIFE15 ENV/SE/000465.

This short introduction of the overall Hg-rid LIFE project is followed by a background to the problem with mercury in general, and specifically from dental amalgam and dental facilities. Thereafter, the purpose and aim of the socio-economic assessment is presented.

## 1.1 Impacts of mercury and dental amalgam

Mercury is a metallic element that in most of its compounds are toxic to both human health and the environment. Mercury and its compounds are present the in ambient air, water basins, and soil. One of the most toxic mercury forms in water is methylmercury (MeHg). High doses of it can be fatal to humans, but even rather low doses can give severe impact on the neurological system and diminish people's intellectual capacity – this effect is sometimes quantified in reduced IQ-points. There are also indications of possible negative impacts on the cardiovascular, reproductive and immune systems. Apart from health effects, negative impacts have been identified on the environment as well. Harmful effects to wildlife comprise e.g. disorder on the nervous system of animals, altered mating habits, affected ability to reproduce, and disturbance of microbiological activity in soils (BIO Intelligence Service 2012).

There are several sources of mercury emissions into water and air, both natural and anthropogenic. The main anthropogenic sources are combustion of fossil fuels, crematories, dumps, landfills, and wastewater treatment plants (Swedish EPA 2019). One of the sources is discarded mercury amalgam from dental

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[1] See the developed web training tool: https://hg-rid.eu/en/home

[2] See website: https://www.praktikertjanst.se/om-oss/socialt-ansvarstagande/miljoprojektet-hg-rid-life/material-och-dokument-hg-rid/

clinics, which by 50% consists of mercury[3]. Dental amalgam is one of the major sources of mercury to municipal wastewater treatment plants, and the main source in the sludge in Sweden (Stockholms vatten 2007; Stockholm Stad 2019). According to the European Parliament and of the Council (2017/852), dental amalgam is also the largest use of mercury in the EU.

In Sweden, policy measures to address the use of mercury came relatively early compared to many other countries. Use of dental amalgam started to be phased out already in 1993 and prohibited in 2009. Since year 2018, no longer any exceptions are approved. Table 1 shows an overview of the phase-out of dental amalgam in Sweden (KemI 2019).

**Table 1 Important years in the phase-out of dental amalgam and mercury in Sweden (KemI, 2019)**

| | |
|---|---|
| 1969 | **Adoption of the Swedish Environmental Protection Act** |
| 1979 | **Introduction of amalgam separators** (voluntary agreement with dentists associations, requiring all dental clinics to be equipped with amalgam separators) |
| 1991 | **Ban for mercury in measuring devices** |
| 1993 | **Phase out of dental amalgam use in temporary teeth** (agreement between the government and the county council associations) |
| 1995 | **Phase out of dental amalgam from children and adolescent dental care** (agreement between the government and the county council associations) |
| 1997 | **Objective to phase out amalgam also in adult dental care** |
| 1999 | **Decision to withdraw fringes for dental amalgam** (cost neutrality) |
| 2009 | **General Mercury ban, including dental amalgam, with some exemptions** |
| 2018 | **General exemptions for use of dental amalgam withdrawn** (possibility to apply for onetime/short term exception will remain) |

On the EU level regulation of dental amalgam was introduced in 2018, with the aim of phasing out the use of all dental amalgam by 2030. Some exceptions are still allowed though (European Parliament and of the Council 2017/852). Today several alternatives to dental amalgam exist, e.g. using composite (plastic) instead.

To reduce mercury discharge to the wastewater, a technique called amalgam separator is used and has been in use in Sweden since 1979. Amalgam separators remove most part of the mercury from water flows. Efficiency rate is estimated at 75– 95%, but it varies depending on accurate installation, use and maintenance (Jacobsson-Hunt, 2007; BIO Intelligence Service 2012). A regulation making it mandatory for dental clinics in EU to use amalgam separators entered into force 1st of January 2019. In Sweden amalgam separators have been in place a long time, due to regulation by the Swedish Environmental Protection Act[4], according to which facilities are expected to use the best available technologies (BAT), including abatement technologies. A voluntary agreement on introducing

[3] Mercury 40-50%, Silver 20-35%, Lead 12-15%, Copper 5-15% and Zinc 2%. Reference: Praktikertjänst, personal communication 2019.

[4] In 1999, environmental legislations where brought together in the Environmental Code (Swedish EPA 2017).

separators from 1979 (KemI 2019), was another instrument encouraging mercury abatement.

However, there is still a large amount of dental amalgam in peoples' teeth. In Hylander and Goodsite (2006) they state that mercury in dental fillings in the population was the second largest stock in 2005[5] of mercury in Sweden: approximately 74% of grown-ups had dental amalgam in their teeth roughly estimated to 40 000 kg. This mercury is gradually released during e.g. dental treatment or loss of teeth. The part of dental amalgam ending up at dental facilities in Sweden is either removed by chair-side filters, or by amalgam separators, or enters the pipes together with the wastewater. In the pipe system the particles can adhere to the pipes and accumulate there over years, or to flow with the wastewater to the municipal wastewater treatment plants. Some of the mercury released from the treatment of amalgam fillings at the facilities is also emitted to air.

Furthermore, there is remaining amalgam in the dental clinic pipes from historical use when it was not yet prohibited. Hence, there is still a risk for contamination and adverse health effects of mercury originating from dental amalgam. Decontamination methods such as the method used within this LIFE-project is one measure to target this remaining mercury.

The focus in this project assessment is mercury discharge from dental clinics to wastewater.

## 1.2. Purpose and aim of the socio-economic assessment

The aim of this report is to present the result of the assessment of the socio-economic impact of the project's actions. Decontamination of dental facilities is a main focus in the report, but we also include an analysis of the amalgam separators. This is done due to two reasons: first, improved use of amalgam separators via training and information is a part of the project; second, the result of this analysis is used to compare the cost-effectiveness between amalgam separators and decontamination, i.e. two abatement measures to reduce mercury leakage from dental clinics.

The assessment includes three different aspects:

1. A cost-benefit analysis of decontaminations performed within the project. Our analysis addresses the costs of reduced mercury leakage to the environment due to decontamination as well as the benefits from reduced negative impacts on human health and the environment. We also conduct a cost-effectiveness analysis of decontamination. Our analyses are scaled up on a regional level (EU wide) as well.

[5] First stock: electrodes in chlor-alkali plants, approximately 400 000kg of mercury. The use of mercury in this industry was phased out by 2010.

2. Analysis of costs and benefits for amalgam separators used by facilities to avoid mercury discharge into wastewater.
3. The impacts of the project in the form of employment effects and the local economy.

### 1.3. Report's layout

In this report, we first describe the two scenarios we are comparing (Chapter 2), and the aspects included in the assessments. In Chapter 3, we present the assessments of socio-economic impacts, including both decontamination and the use of amalgam separators. The analyses start with presenting the methods and input data used, followed by results and finally a sensitivity analysis. Chapter 3 also includes our up-scaled analysis on the EU-wide level, analysis of effects on the local economy and employment, and finally a comparison of cost-effectiveness with other available studies. The last chapter presents the discussion of our results and the final conclusions of the socio-economic assessment.

# 2. Decontamination scenario and reference scenario

In our main analysis, a decontamination scenario is compared to a reference scenario. The **reference scenario** represents a hypothetical case meaning that no decontaminations at dental clinics are performed, and mercury adhered to the pipes would be, sooner or later, released into the environment. In the **decontamination scenario**, corresponding to the project's situation, mercury[6] has been removed (to a large part) from the pipes and, subsequently, from the environment.

In both scenarios, we assume that amalgam separators are used at all the considered facilities, which means that most part of the incoming mercury has already been removed prior to the wastewater stage. Costs and benefits of amalgam separator use are analysed separately and presented in Chapter 3.2.

To analyze potential costs and benefits of decontaminations and amalgam separators on an EU level, we scale up the results of the cost-benefit analyses to a larger number of clinics, based on estimates of number of dental facilities in the EU.

**Socio-economic consequences of the decontamination scenario**

The decontamination scenario results in a range of consequences included in the socio-economic analysis presented below.

**Environmental and health benefits** result mainly from decreased adverse effects on health and environment due to mercury removal from the pipes, and consequently, from the pathways leading to recipients. Quantification of the related external costs depends on the methods for monetary valuation of mercury releases, discussed in Chapter 3.1.1.3.

On the other hand, there are some adverse effects related to decontaminations. Decontamination procedures imply road trips to the decontaminated clinics, and transportation of the collected sludge containing mercury and other metals (silver, tin, copper, zinc) to the storage site. Furthermore, sludge is approximately once a month transported to Germany for treatment at the Medentex facility[7]. Emissions of $CO_2$ from decontamination-related transport are also considered as an important consequence and thus included in the analysis.

**Decontamination-related costs** comprise the following cost components:

1. *Costs of decontamination procedure*, including wages covering cost of working and travel time, cost of equipment and materials (chemicals),

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[6] And other metals like silver, tin, copper and zinc, which are also part of amalgam, however, the focus of the project is on mercury.

[7] Sweden Recycling is Medentex's sister company. Medentex is located in Bielefeld, Germany, and handles the waste and sludge, and where their mercury analysis laboratory is situated.

cost of transport to the clinics and transportation of collected sludge and water, and cost of further treatment at Medentex.

2. *Costs of closing a clinic during decontamination* – these are indirect costs related to the lost working time during decontamination;
3. *Costs of application handling* relate to fees clinics have to a local environmental authority for processing and getting approved their applications for decontamination.

**Effects on local employment and economy** of the project is also assessed.

# 3. Assessment of socio-economic impacts

In this chapter, we describe and value the consequences of the decontamination scenario, compared to the reference scenario defined above (Chapter 2). This is the main part of the analysis, illustrated in Figure 1. Within cost-benefit analysis, we estimate gross and net benefits from decontamination and use of amalgam separators, compare them to costs and make conclusions about whether positive net benefits (implying social welfare increase) are achieved. Sensitivity analysis investigates how the results are affected by variations in certain crucial input parameters. Assessments of cost-effectiveness include e.g. analysis of costs to remove 1 kg mercury, and comparisons of possible alternatives to do this. In addition, we analyze the effects of the project on local jobs and economy.

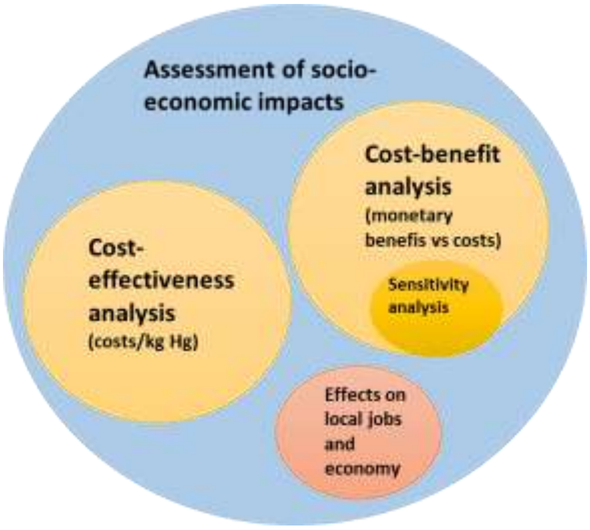


**Figure 1. Structure of the socio-economic assessment within the project**

The results are then compared to relevant results from similar studies.

## 3.1. Costs and benefits of decontamination

In the cost-benefit analysis of decontamination, we compare total societal costs related to performed decontaminations with the corresponding reductions of the external costs resulting from mercury removal from the environment.

### 3.1.1. Decontamination: Method and input data

Cost and benefit estimates in the analysis of decontamination comprise the total "one-time" internal and external costs per decontamination, which is assumed to be a rather rarely (about once in 10 years) performed procedure. No annual estimates are done, but we calculate the total costs and benefits from a once performed mercury removal from the environment, even though the damage from leaking mercury (if it had not been removed) would be happening over a long time.

Assessment of decontamination is performed based on the data of **68 facilities**, for which the results of the abatements were available by July 2019.

#### 3.1.1.1. Assumptions and limitations

In the valuations of external cost, we include damage from mercury discharge to dental clinics' wastewater, and climate effects of $CO_2$ emissions from transportation of collected mercury sludge and decontamination water. These are not the only effects of decontamination: for instance, we exclude from the analysis emissions of harmful air pollutants, also occurring during transportation.

Metals other than mercury – silver, tin, zinc and copper – are removed during decontamination as well, since they also are a part of dental amalgam. The benefits from removing these metals are, however, not included in the analysis. This is due to first, the analysis of the sludge and water from decontaminations do not include measurements of these metals; second, most of these metals are not removed from the ecosystem but mainly recycled back on the market.

During decontamination, certain part of the mercury in the pipes are emitted to air. Measurements performed within the project show elevated concentrations of mercury in the air during and shortly after decontamination, compared to the normal conditions (Stripple & Nerentorp, 2019). Environmental and health effects of these emissions are not included in the current analysis.

We assume that for transport within Sweden and between Sweden and Germany, trucks with very similar characteristics and loaded to the same extent are used. The total distance for transportation within Sweden is slightly overestimated since some decontaminations in more distantly located cities are done without returning to the SRAB base in Växjö – this is not accounted for in the calculations. At the same time, the average distance for the transportation between Sweden and Germany is underestimated: certain additional rides in Germany related to sludge treatment are not accounted for due to confidentiality. We assume that these two issues offset each other. As further analysis shows, the relative contribution of $CO_2$ emissions to the total monetary value of the estimated effects is anyway insignificant. Other potential increase in $CO_2$ emissions from e.g. energy use for the handling of mercury at the plant in Germany is not considered. More details about the environmental impacts from the whole decontamination life-cycle can be found in Stripple & Nerentorp (2019).

An important assumption concerns faith of the mercury adhered to the pipes, if not removed by decontamination (the reference scenario). We assume that all that mercury will sooner or later be discharged into the wastewater from dental facilities. Further distribution of mercury in the wastewater between different pathways, and its ultimate faith after the wastewater treatment facilities, is estimated in Concorde East/West Sprl et al, 2012. According to this source, 30% ends up in air, 35% in soil, and 35% in water. We use these assumptions in the cost-benefit analysis. Environmental and health impacts of mercury in different media are valued differently, as described below in Chapter 3.1.1.3.

All monetary results of our calculations are presented in €$_{2018}$. For recalculation between valuations from different years, we use Consumer Price Indices (CPIs) by OECD, and for recalculation between SEK and Euro, as well as Euro and USD and NOK – exchange rates of the European Central Bank[8].

#### 3.1.1.2. Input data

Input data for the cost-benefit analysis presented in this chapter, and their sources, are summarized in Table 2. Decontaminations have been performed at 68 facilities, and certain parameters vary greatly between facilities – for such parameters, we present minimum, maximum, mean and median values from the available range.

**Table 2. Input data for cost-benefit analysis of decontamination**

| Parameter | Unit | Min | Median | Mean | Max |
|---|---|---|---|---|---|
| Mercury collected, per clinic[1] | g | 3.6 | 105 | 297 | 2354 |
| Mercury-containing sludge collected, per clinic[1] | kg | 0.3 | 3.0 | 4.7 | 25 |
| Decontamination water used, per clinic1 | kg | 50 | 110 | 120 | 360 |
| Cost of working hour at dental facilities[2] | €$_{2018}$/hour | | | 416 | |
| Cost of working hour at environmental authorities handling applications[3] | €$_{2018}$/hour | | | 108 | |
| Working time (=*closed facility* time), per clinic[1] | hours | 0.5 | 3.5 | 3.9 | 8 |
| Travel time, per clinic[1] | hours | 0.5 | 3.5 | 4.5 | 15 |
| Time of handling applications, per clinic[2] | hours | | | 2.5 | |
| $CO_2$ emission factor[4] | kg/t-km | | | 0.041 | |
| One-way travel distance within Sweden[1] | km | 10 | 230 | 273 | 932 |
| One-way travel distance between Sweden and Germany[1] | km | | | 830 | |

[1] Sweden Recycling, personal communication during 2019 and decontamination reports
[2] Praktikertjänst, personal communication during 2019
[3] Miljösamverkan, 2018
[4] Same as in the LCA analysis presented in Stripple & Nerentorp 2019

Decontaminated clinics use either wet or dry suctions systems, which may affect amounts of mercury going to the pipes and adhering there. More than half of the decontaminated facilities use wet systems. For decontamination of clinics with wet suction systems, different types of chemicals may be used. Clinics with dry suction systems were decontaminated without use of chemicals.

#### 3.1.1.3. Valuation of environmental and health effects

This sub-category of input data is presented separately since valuation of environmental and health effects resulting from mercury removal during decontaminations has crucial impact on the result of the cost-benefit analysis. We thus discuss in detail numbers that have been chosen for monetary valuation of mercury, their sources and underlying assumptions.

[8] Average rate over the period January 2017 – May 2019.

**Mercury - Hg**

To include in the CBA the effects of pollution from the mercury released from the dental clinics, we have conducted a literature review to explore the possibilities to use methods and valuations from previous studies, see Annex 1. The focus has been on emissions to water since the decontaminations take place in the waterfilled pipes, but as seen in Chapter 3.1.1.1, our assumption is that mercury released from the clinics with the wastewater is in the end distributed between air, soil and water. This is because mercury entering the water treatment plants is redistributed and leaves the plants with the water and sludge, which can be further treated in different ways (e.g. incinerated or spread on the agricultural soil) before the final disposal. Hence our review has focused on finding valuation methods for mercury released to these three media.

There is a lot of scientific literature on the valuation of mercury, however, mainly focused on emissions to air. Due to the complex formation cycle and dispersion of mercury, which health effects (apart from IQ loss) to include in the valuation is still a subject to scientific debate. Two previous studies conclude that it is neither possible to quantify this cost accurately nor to recommend a generalized valuation of mercury (BIO Intelligence Service 2012; Dubourg 2018). One of the approaches to tackle this problem mentioned in the literature is to compare abatement costs instead (see e.g. ECHA 2010; Hylander and Goodsite 2006; Vandeven and McGinnis 2005). In e.g. ECHA (2010) they use a benchmark value of 10 000 Euro/kg mercury as an indicator to ensure a proportionality of abatement costs related to the risk of mercury, i.e. indirectly assuming that the risk of negative health and environmental effects of the release of 1 kg of mercury is not valued higher than 10 000 Euro.

There are to our knowledge at least two methods attempting to give a generic value of released mercury to water, air and soil. The first one is the EPS database (Steen 2015); this value is approximately 20 Euro/kg mercury released to water. The same value is also applied for emissions to air. These are generic, global average values of mercury’s health impact on humans; the impact included in the valuation is intellectual disability via brain damage (i.e. damage cost via valuation of lost statistical years), where the main intake of mercury is via fish consumption. The EPS method addresses soil in a different way, estimating not the health effects but rather the value based on depletion of scarce mercury reserves. This estimate is 54 298 Euro/kg. All these three values are not place-specific, hence there are no specific values for the situation in Sweden.

The second method is called the Ecotax Method, developed in Sweden for weighting values in Life Cycle Analysis. This method is not based on individual preferences but instead on political preferences via taxes and fees. With this method values have been estimated for both human health and ecosystem effects, via human toxicity and aquatic toxicity (Johansson 1999). For human toxicity, monetary values are calculated using human toxicity potentials, which together with Swedish tax rates are used to estimate specific costs for heavy metal emissions, e.g. mercury. The estimated values in SEK[9] per kg of mercury to water is 7 100, to air 7 000 and to soil – 74 000. For aquatic toxicity, the monetary values are based on aquatic ecotoxicity potentials for emissions to water and soil from Jolliet and Crettaz (1997) and Swedish taxes and fees (Johansson 1999). Their estimates generate the value of 5000 SEK/kg of mercury to water, 75 000 to soil and 41 000 to air. The taxes and fees used for estimating the values of emissions to water are 180-350 SEK/kg lead in petrol, to air – 20 SEK/kg copper in anti-fouling paints and to soil 30 000 SEK/kg cadmium in fertilizers. We have recalculated the value for mercury to soil based on the new suggested fee on cadmium in pesticides and fertilizers of 200 000 SEK/kg (SOU 2017). For the other taxes and fees an update has not been feasible[10].

The values presented in Table 3 below are selected as input to the cost benefit analysis and recalculated to the 2018 price level. We have selected these values to capture both health and environmental impacts with one method, also using Swedish valuations since this is the studied area within the project.

**Table 3 Valuation of mercury in Euro/kg Hg**

| Impact | Media | Unit | Value |
|---|---|---|---|
| Human toxicity | Air | €$_{2018}$/kg Hg | 1 200 |
| | Soil | | 47 500 |
| | Water | | 1 200 |
| Aquatic toxicity | Air | | 6 900 |
| | Soil | | 48 500 |
| | Water | | 840 |

Source: Johansson (1999)

The generic values, however, are associated with uncertainties, and as seen from the literature review, the values vary greatly. This depends, among others, on the complexity of the dispersion of mercury, selected methods and impacts included. Since outcomes of our analysis depend to a high extent on the selected values, we use minimum and maximum values as well, to generate a range indicating the degree of uncertainty. Minimum and maximum values are calculated by combining estimated in the literature different monetary low and high values per kg of mercury to air, soil and water, respectively. All of these selected values are based on individual preferences, e.g. willingness-to-pay and value of a statistical life /disability adjusted life years. Note that these values do not attempt to include environmental effects, only health-related. For more details, see Annex 2. These calculated value combinations, as well as the values from Table 3, are then weighted with the assumed distribution of mercury from the clinics' pipes to the environment: 30 % to air, 35 % to water, 35 % to soil (see Chapter 3.1.1.1 for this assumption). This results in the values we use in our cost benefit analysis and in the sensitivity analysis. Values used are shown in Table 4. Note that our central value is chosen from Johansson (1999) since it captures both health and

[9] 8.44SEK/EUR (Year 2000).

[10] Petrol sold today is lead-free, and no fee is longer applied in anti-fouling paint.

environmental impacts with one method and uses Swedish valuations, which is in line with the project's studied geographical area.

Table 4 Weighted monetary values of mercury used in our analyses, in €$_{2018}$/kg Hg

| Impact | Media | Unit | Low | Central | Max |
|---|---|---|---|---|---|
| Human health | Air, Water & Soil | €$_{2018}$/kg Hg | 23 | 36 700[11] | 86 500 |

Sources: Steen (2015), Anthesisenveco (2017), Rice & Hammitt (2005), Johansson (1999), and own calculations.

## Greenhouse effect - $CO_2$

The monetary valuation of $CO_2$ used in our analysis is based on the numbers summarized in Table 5. As for mercury, we have picked a central value for our main analysis, and a minimum and maximum value for the sensitivity analysis. Central and high-end values are adopted from Korzhenevych et al. (2014) – the Handbook on external costs of transport developed for the European Commission. These numbers are based on estimates of avoidance costs corresponding to efforts required to stabilize global warming at 2°C, see reasoning in Chapter 2.5.1.4. of the Handbook. As low-end value, we use the current market carbon price according to the EU Emission Trading Scheme (EU ETS).

Table 5. Economic values per tonne of $CO_2$- emissions used in this analysis.

| Economic value of $CO_2$ | | Unit | Source |
|---|---|---|---|
| Low | 25.5 | €$_{2018}$/t $CO_2$ | Current (Febr. 2018) EU ETS market price[12] |
| Central | 101 | €$_{2018}$/t $CO_2$ | Korzhenevych et al. 2014, central value |
| High | 188 | €$_{2018}$/t $CO_2$ | Korzhenevych et al. 2014, high-end value |

### 3.1.2. Decontamination: Results

Decontamination-related costs and environmental and health benefits are described in detail in this chapter, together with the results of the cost-effectiveness analysis of the decontamination procedure.

#### 3.1.2.1. Decontamination: Cost-effectiveness analysis

Decontamination-related costs, as briefly mentioned in Chapter 2, consist of three main components: costs of decontamination procedure itself, costs of closing a clinic during decontamination, and costs of application handling by environmental authorities. Part of these costs are not paid by clinic but subsidized by the European Union within the presented project. From the societal perspective, however, it does not make any difference, which is why we count in full decontamination costs in the analysis.

The total decontamination-related societal costs of all the decontaminations performed within the project are estimated at app. 350 thousand Euro. The costs

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[11] Also includes environmental impact, in the form of aquatic toxicity.

[12] http://www.nasdaqomx.com/commodities/todays-trading, as of 2019-05-24

vary greatly between facilities – from 2.8 to 9.4 thousand Euro per clinic, with the average value of 5.1 thousand Euro per clinic.

Variation in the relative contributions of different cost components in the total decontamination-related costs are illustrated in Figure 2. About 63% is the costs of the decontamination procedure itself. The costs for closed facility account for 32% of the total, on average, although for some facilities they can be higher than decontamination costs. Contribution of the costs of handling applications is relatively small – around 6%.

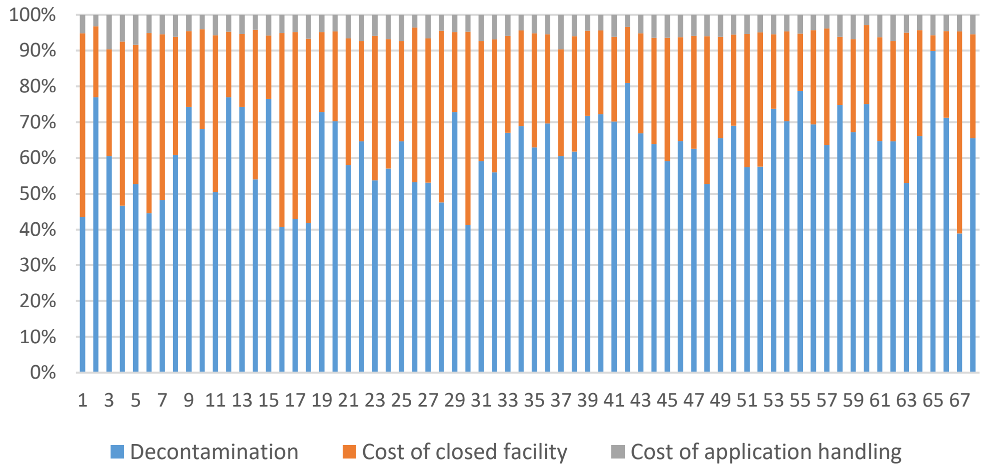


**Figure 2. Decontamination-related costs of dental clinics – relative contributions of different cost components**

Decontamination-related costs per kilogram of mercury removed from the environment (cost-effectiveness) are presented in Table 6. Significant differences between the mean and the median values are caused by large variations between clinics regarding both decontamination-related costs and amounts of collected mercury.

**Table 6. Cost-effectiveness, variation between facilities**

| Type of costs | thousand Euro/kg removed Hg | | | |
|---|---|---|---|---|
| | Min | Mean | Median | Max |
| Total internal costs | 1.7 | 17.3 | 50 | 1209 |
| Decontamination costs | 0.9 | 10.9 | 31 | 792 |
| Costs of closed facility | 0.5 | 5.5 | 18 | 342 |
| Costs of application handling | 0.1 | 0.9 | 2.6 | 75 |

Costs of the decontamination procedure itself is determined by a range of parameters, such as type of the suction system, equipment and chemicals to be used, working time needed and travel time, depending on the clinic's location. The total time spend for one decontamination procedure ranges from 2.5 to 23 hours (mean value – 8.4 hours), where working time and travel time constitutes about 50% each, on average.

Figure 3 illustrates differences in the cost-effectiveness between:

- Clinics with wet and dry suction systems;
- Clinics with wet suction systems decontaminated with and without use of chemicals.

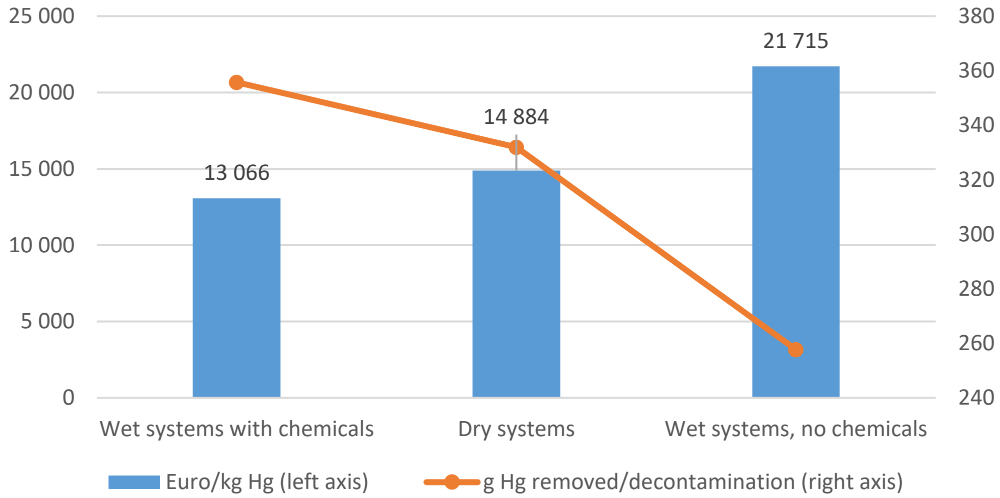


**Figure 3. Cost-effectiveness of decontamination, differences between facilities with different suction systems and between facilities with wet suction systems decontaminated with and without use of chemicals**

Figure 3 indicates that use of chemicals for clinics with wet suction systems allows to collect 38% more mercury per facility than in case if decontamination is performed without chemicals. It also results in significant differences in the costs per kg removed mercury – 13.1 thousand Euro/kg Hg for clinics decontaminated with chemicals vs. 21.7 thousand Euro/kg Hg – for clinics with wet systems decontaminated without chemicals. For clinics with dry suction systems, amounts of collected mercury per facility is lower than for clinics with wet suction systems (if no chemicals are used) - 14.9 thousand Euro/kg Hg.

#### 3.1.2.2. Decontamination: Cost-benefit analysis

Environmental and health benefits of decontamination result from reduction of the relevant external costs. External costs included in this analysis cover mainly harmful effects of mercury leaking from dental clinics’ pipes to the wastewater. Positive effects from mercury removal at decontamination are to a certain extent counteracted by climate impacts from transport-related $CO_2$ emissions.

The total amount of removed mercury within the project is **20.2 kg**. This number corresponds to the **gross environmental benefit** of **740 thousand Euro**. The amount of removed mercury per facility varies from 3.6 g to 2.4 kg (mean – 297 g, median – 105 g).

Total $CO_2$ emissions from decontamination-related transport within the project are estimated at 700 kg. Per decontamination, this number varies from 6.3 kg to 21 kg (mean – 10.3 g, median – 9.6 g). This equals to the total damage of 70 Euro. The counteracting negative climate effect of $CO_2$ emissions is thus negligibly small compared to the environmental and health benefits due to mercury removal from the environment.

For facilities with dry suction systems, gross benefits per decontamination are by 5% higher than for facilities with wet suction systems, if chemicals are not applied. The average gross benefit value for facilities with wet suction systems is 9.9 thousand Euro. Introduction chemicals into decontamination results in the value of 13.1 thousand Euro.

Net benefits are the difference between gross benefits and decontamination-related costs. The **total net benefits** gained within the project due to decontamination is estimated at **393 thousand Euro**.

Since decontamination-related costs vary less than amounts of collected mercury, the net benefits per facility would be determined mostly by these amounts. This is illustrated in Figure 4, where dots represent clinics, and the green area corresponds to the clinics that gain positive net benefits from decontaminations – they are 27 of 68. For the rest of the clinics, collected amounts of mercury are too small so that the gross benefits do not overweigh the decontamination-related costs, and decontamination does not result in positive net benefit. The break-even point lies around 157 g mercury.

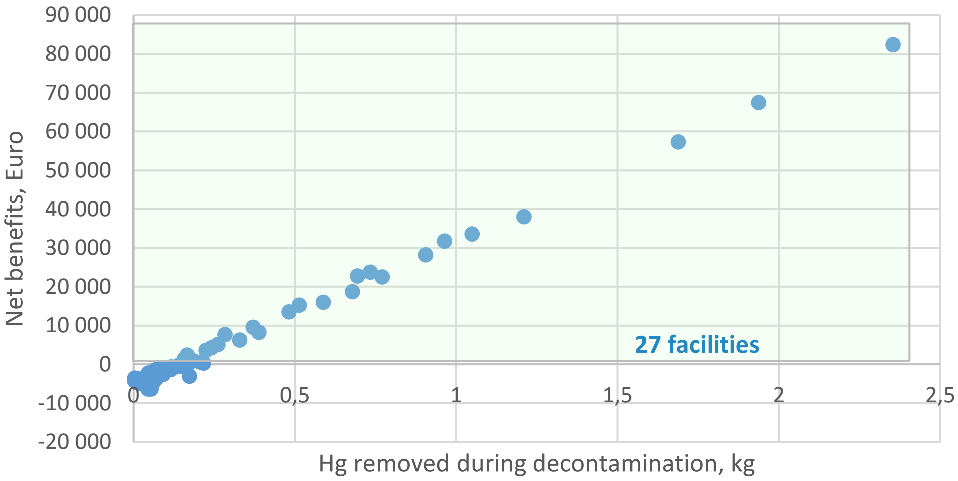


**Figure 4. Net benefits depending on the amounts of removed mercury**

The total costs and benefits of the 68 decontaminations performed within the project are illustrated in Figure 5.

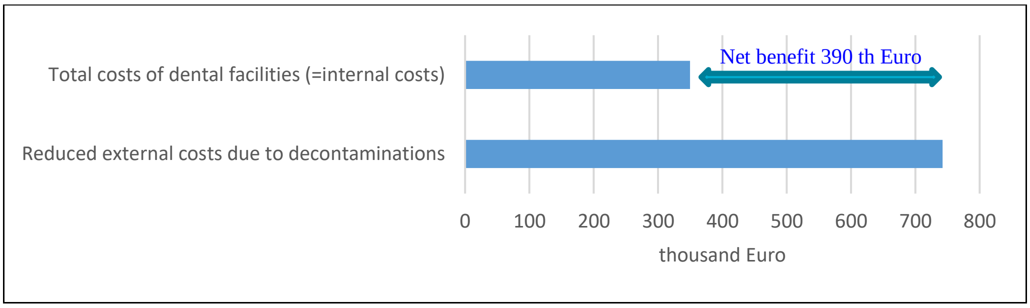


**Figure 5. Total costs and benefits of all decontaminations within the project**

Benefit-to-cost ratio is 2.1 for the entire project, meaning that the gross benefits are higher than the costs, and the project results in the positive net benefits (390 thousand Euro) to society. However, there is a significant variation between the facilities – from 0.03 to 22. The average value is 2.4 while the median is 0.74 implying that for more than a half of the clinics decontamination does not result in positive net benefits. This is also seen in Figure 6 illustrating variations in benefit-to-cost ratio for the clinics included in the project.

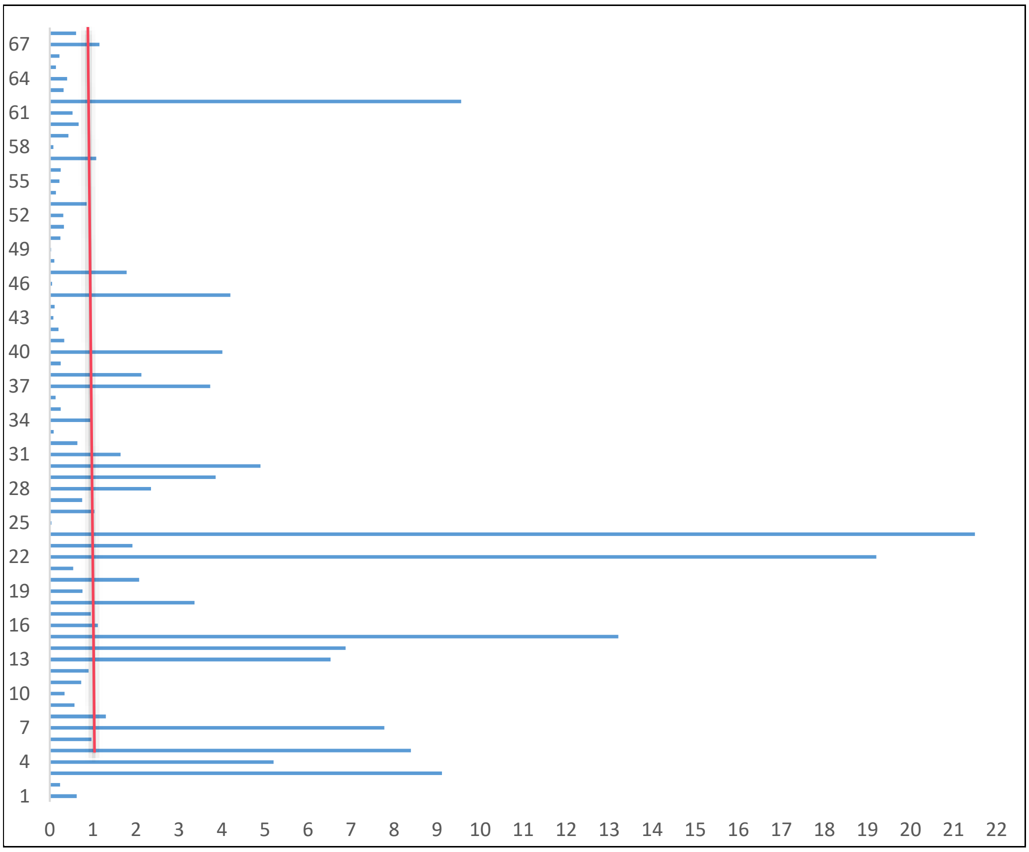


**Figure 6. Benefit-to-cost ratio (x-axis) of decontaminations: variation between the facilities; red line corresponds to benefit-to-cost ratio= 1, if it is above 1 a decontamination results in positive net benefits.**

The costs and benefits also vary depending on the combination of the suction system and use of chemicals during decontamination. Figure 7 illustrates how the total gross benefits and the costs relate to each other for clinics with different suction systems, and for clinics where chemicals were used for decontamination. The total gross benefits achieved by decontamination of clinics with wet systems without use of chemicals, and clinics with dry system are similar (app. 320 thousand Euro each), while the facilities where chemicals were used contribute to app. 90 thousand Euro of the total project benefits. This is because the total number of facilities where chemicals were used is low – 7 of 68 decontaminated within the project. Actual effect of the use of chemicals is illustrated by benefit-to-cost ratio, which increases from 1.7 to 2.8 between the cases without and with chemicals. Decontamination of clinics with dry systems seem to be more beneficial than decontamination of clinic with wet systems without use of chemicals: while the total benefits are similar, the total costs are by 43% higher for the clinic with wet suction systems.

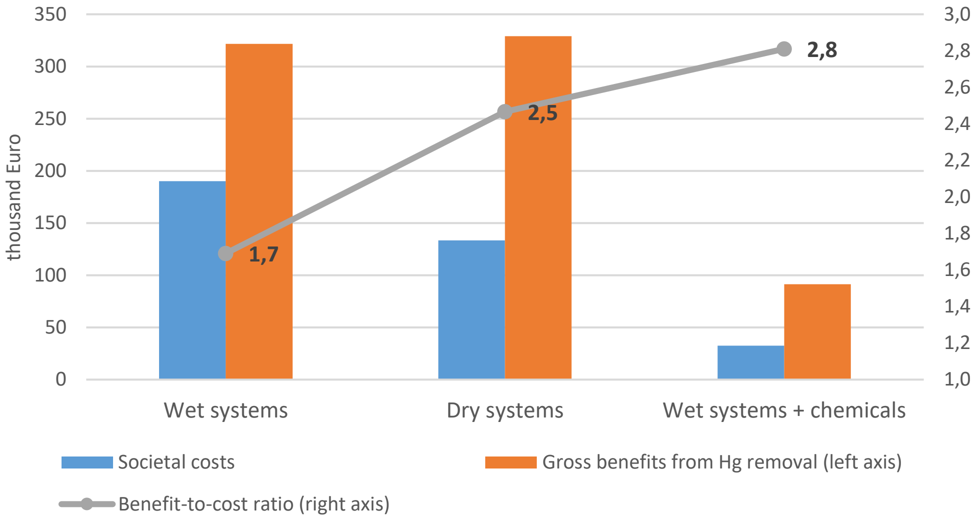


**Figure 7. Total costs and benefits of clinics with different suction systems (wet and dry) and clinics with wet suction systems and chemicals been used during decontamination**

Environmental and health benefits resulting from decontamination can be estimated in different ways. In the analysis above, benefits are estimated via the total amounts of removed mercury, available for each of the decontaminated facilities. Another way to make such evaluation is to analyze mercury concentrations in wastewater from dental facilities. The purpose of the decontamination is to decrease amount of mercury leaking from the pipes into environment via wastewater. Mercury concentrations in wastewater before and after decontamination can thus be considered as a criterion for the procedure's efficiency. Evaluation of decontamination effects via mercury concentrations in the wastewater, considered as side-analysis, is summarized in Annex 3.

#### 3.1.3. Decontamination: Sensitivity analysis

In the sensitivity analysis presented below, we investigated to what extent the results are affected by two parameters with the wide interval of possible values

– valuation of the mercury effects, and amount of mercury collected during decontamination.

#### 3.1.3.1. Valuation of environmental and health effects

In the results of the main results presented above, we used the central valuation of harmful mercury effects from Table 4, Chapter 3.1.1.3. However, the low-to-high range is so wide (23 – 86 525 Euro/kg Hg) that the choice of valuation is crucial for the results of the cost-benefit analysis. Below, we present the numbers for costs and benefits of decontamination, obtained with both low and high values, to illustrate the effects on the results.

The overall **benefit-to-cost ratio of the entire project** increases from 2.1 to 5.0 at the high-end valuation, resulting in the total net benefits of app. 1 400 thousand Euro. At the low-end valuation, the costs (app. 350 thousand Euro) are significantly higher than the gross benefits (450 Euro), generating a negative net benefit. This is illustrated in Figure 8. The break-even point lies around the value of 17 300 Euro/kg Hg – if benefits are valued lower, the projects costs are higher than the benefits.

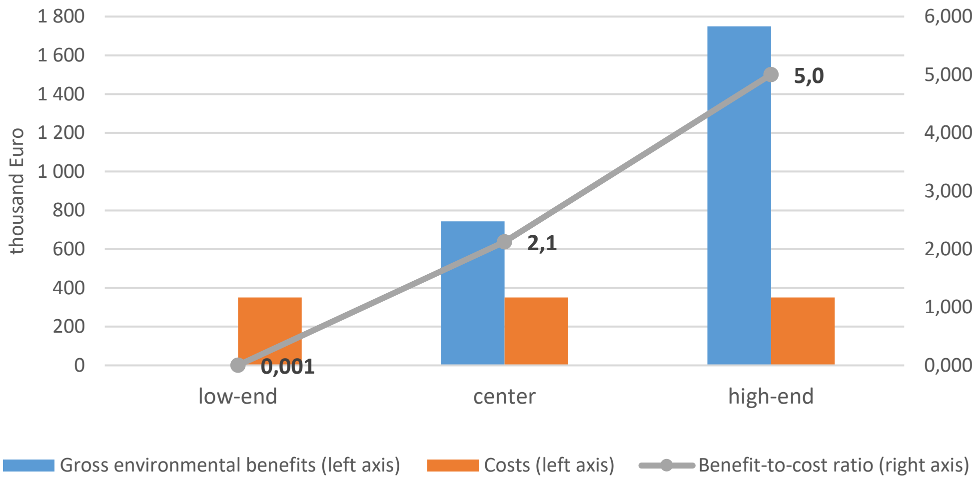


**Figure 8. Costs and benefits of the project depending on the valuation of mercury effects**

The number of facilities with decontaminations resulting in positive net benefits is increasing from 27 at central valuation to 43 at high-end valuation, see Figure 9. The minimum amount of collected mercury needed for decontamination to generate a net benefit decreases from 157 g to 47 g. Maximum net benefit from one decontamination increases from 82.4 thousand Euro (central valuation) to 200 thousand Euro (high-end valuation).

If the low-end valuation is used, none of the decontaminations result in positive net benefits for society.

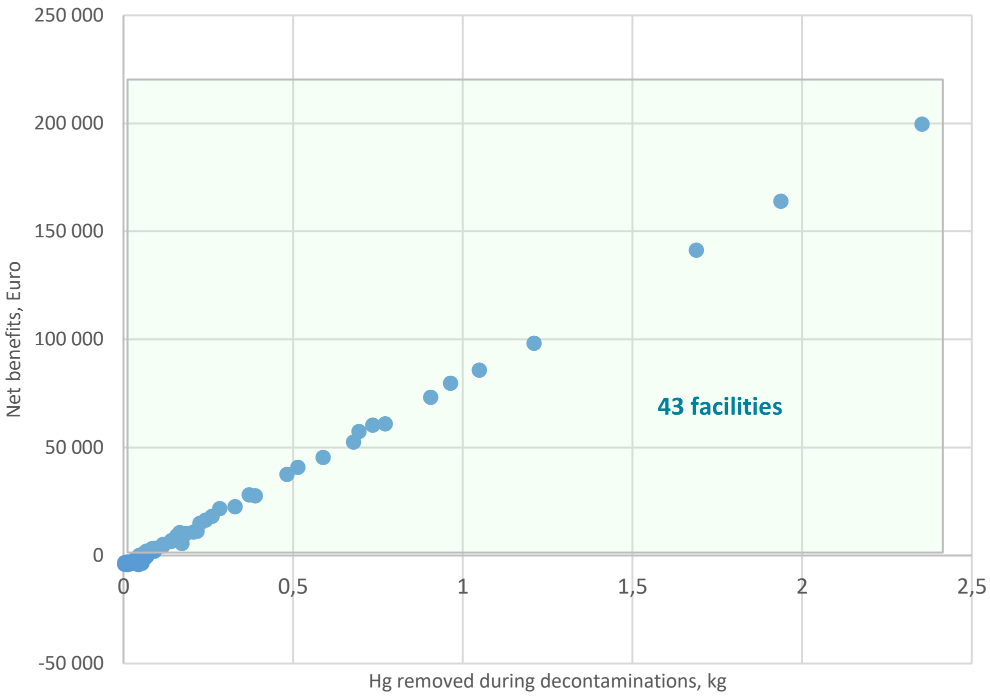


**Figure 9. Net benefits depending on the amounts of removed mercury, high-end valuation**

#### 3.1.3.2. Amount of removed mercury per decontamination

As the results of the main analysis show, decontamination does not always result in the net benefits for society. It partly depends on the value we set on mercury effects, but also on the amount of mercury collected. This amount ranges from 3.6 g to 2.4 kg per decontamination and depends on the pipe material, incline, suction system, years since the last decontamination, type and efficiency of amalgam separator used, and certain others. It is thus difficult to say in advance how much mercury will be collected and whether a decontamination will bring net benefits.

Figure 10 shows how the benefit-to-cost ratio is affected by the amount of mercury that can be collected within a hypothetical next decontamination. We assume that decontamination-related costs are the same as the mean value for already completed decontaminations (5100 Euro/decontamination). The whole range of 3.6 g – 2.4 kg is presented (X-axis), and benefit-to-cost ratio (Y-axis) is estimated for low-end, central and high-end valuations.

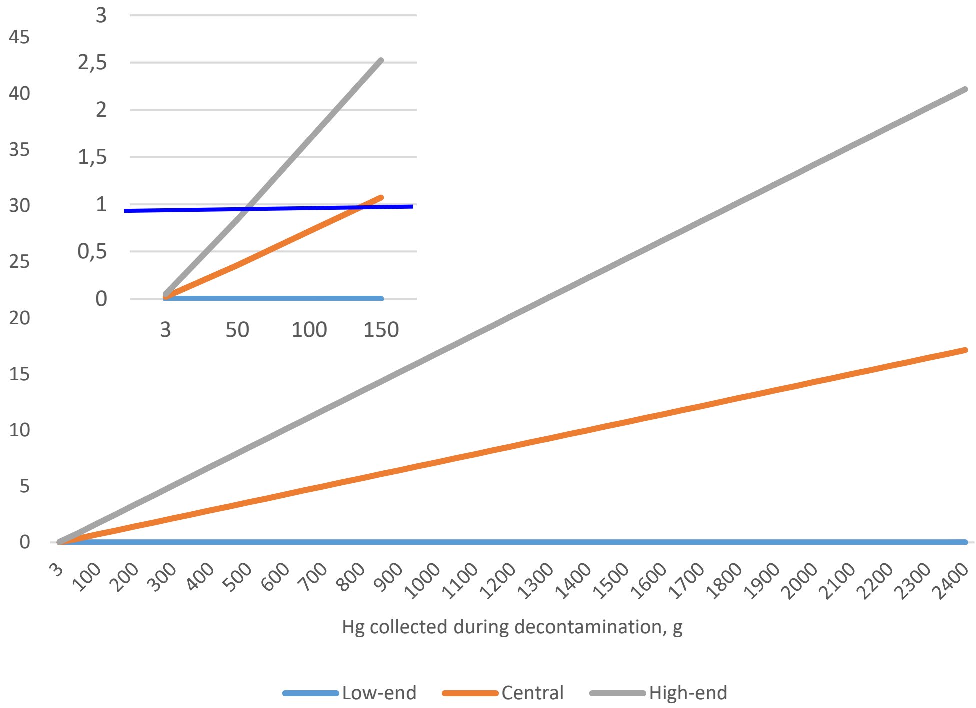


**Figure 10. Benefit-to-cost ratio (Y-axis) of a next decontamination depending on the amount of collected mercury; Y=1 corresponds to a break-even point above which a decontamination would result in positive net benefits**

Net benefit is positive if benefit-to-cost ratio is higher than 1. For central valuation, this corresponds to the mercury amount of 140 g – this is the minimum amount that should be collected in order for a decontamination to result in net benefit for society. If we chose high-end valuation, the minimum amount is lower – 60 g. At the low-end valuation, positive net benefit cannot be achieved until the amount of collected mercury is over 200 kg, which is not a realistic option.

Figure 11 illustrates the range of potential net benefits per decontamination depending on the chosen monetary valuation of mercury's effects and on the amount of collected mercury (assuming mean value of the decontamination-related costs). This comparison indicate that collected amount of mercury, based on the actual data obtained within the project, is associated with even larger uncertainties than valuation of environmental effects of mercury.

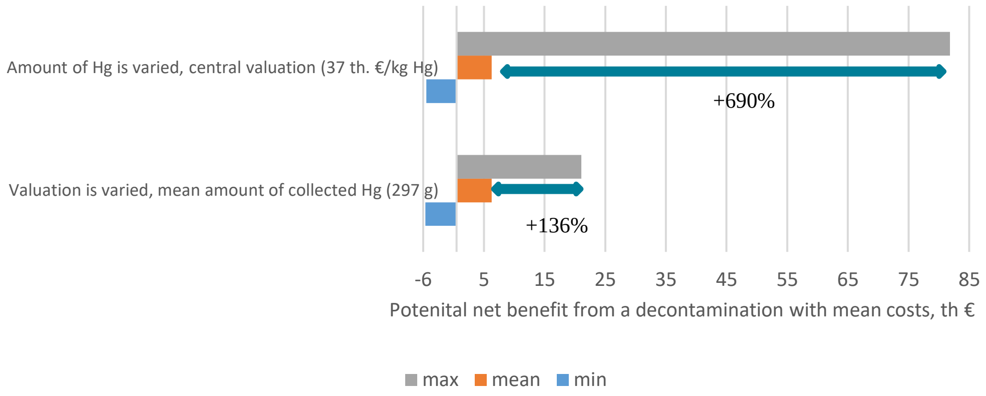


**Figure 11. Net benefits per decontamination depending on the chosen valuation and on the amount of collected mercury**

## 3.2. Costs and benefits of amalgam separators

Amalgam separators are a technology to remove mercury from environment before it enters facility's wastewater flow. From January 1st, 2019, use of amalgam separators is obligatory in the EU. In the analysis presented below we focus on the costs and benefits of amalgam separators, compared to the situation when they are not in use.

### 3.2.1. Amalgam separators: Method and input data

In the cost-benefit analysis of amalgam separators, we compare total societal costs of separators with the corresponding reductions of external costs resulting from mercury removal from the environment. Unlike decontamination, which is usually not performed more often than once in 10 years, an amalgam separator is a constantly used technique preventing large part of mercury in dental amalgam from ending up in the clinic's wastewater. We have thus chosen to analyze **annual costs and benefits per separator**.

Like for decontamination, $CO_2$ emissions from transportation of mercury-containing waste from amalgam separators are included in the analysis. Other potential negative and positive effects are excluded from calculation of external costs. Valuation of mercury's health and environmental impacts are the same as described in Chapter 3.1.1.3.

Costs of clinics include investment costs, costs of working time for daily maintenance, and costs of waste treatment. Waste from separators, consisting mainly from amalgam sludge, and separators are sent to Germany (Medentex) together with the sludge and water from the decontaminations. Proper functioning and high removal efficiency of amalgam separators is maintained by regular emptying coarse particle filters installed prior to separators. A lifetime of a separator is assumed to be 10 years – this is the number used for annualisation of investment costs, together with an interest rate of 4%. Cost annualization is done according to the following equation:

$$I_{an} = I * \frac{(1+q)^{lt} * q}{(1+q)^{lt} - 1}$$

Where:
$I_{an}$ = Annual investment costs (€)
$I$ = Total investment costs (€)
$q$ = Investment interest rate (shares)
$lt$ = Investment lifetime (years)

The current project was not focused on amalgam separators, and detailed data by facility are therefore unavailable. Input parameters used for calculations, summarized in Table 7, are therefore expert estimates, often average numbers over a large number of facilities.

**Table 7. Input data used for cost-benefit analysis of amalgam separators**

| Parameter | Value | Unit | Affects |
|---|---|---|---|
| Hg amount in waste sludge from one separator[1,4] | 22 | g | Benefits |
| Weight of amalgam separator filled with sludge[1] | 7.5 | kg | Costs |
| One-way travel distance for sludge transportation[1] | 830 | km | Costs |
| $CO_2$ emission factor[3] | 0.041 | kg/t-km | Costs |
| Investment costs[1] | 688 | € | Costs |
| Time for daily maintenance[2] | 5 | min/day | Costs |
| Working days per year | 230 | days/year | Costs |
| Salary of employees responsible for daily maintenance[2] | 2880 | €/month | Costs |
| Cost of changing a separator (includes costs of waste treatment)[1] | 133 | € | Costs |
| Number of changes per year[1,4] | 1.3 | times/year | Benefits and costs |

[1] Sweden Recycling, personal communication during 2019 and decontamination reports, and price list.
[2] Praktikertjänst, personal communication during 2019
[3] Same as in the LCA analysis presented in Stripple & Nerentorp 2019
[4] Medentex, personal communication during 2019

### 3.2.2. Amalgam separators: Results

Calculation shows that the annually removed mercury by one amalgam separator amount of mercury is, on average, 29 g. This corresponds to the environmental benefit of 1 050 Euro. External costs of $CO_2$ emitted during transportation of amalgam separators filled with sludge (0.6 kg in total per separator) are 0.06 Euro, which is negligibly low in comparison to the cost of removed mercury. Related annual costs paid by dental clinics per amalgam separator amount to 400 Euro per year. The net benefit is thus 650 Euro/year per amalgam separator. The benefit-to-cost ratio is 2.7.

The average number of amalgam separators per clinic included in the project is 2.7[13]. Thus, the total net benefit of using amalgam separators at 531 facilities screened[14] within the current project is app. 350 thousand Euro.

#### 3.2.2.1. Amalgam separators vs decontamination

To compare benefits from using amalgam separators with benefits from decontamination, the same time horizon should be used. Decontamination is suggested to be made on average once in 10 years, which is why we scale up costs and benefits of amalgam separators to the same period. Investment costs are in this case not annualized but we use the total investment costs (688 Euro/separator) since their lifetime is also 10 years. As a result, benefit-to-cost ratio becomes slightly higher – 2.8. The results for amalgam separators are also multiplied with the average number of amalgam separators per clinic = 2.7.

Comparison between amalgam separators and decontamination as two possible alternatives to remove mercury is summarized in Table 8. This comparison, however, is not meant as support for a choice between these two options: use of amalgam separators is mandatory for all dental clinics in Sweden, while decontaminations are usually not. Moreover, they are partly used for different purposes. Decontaminations are performed in clinics that have already installed separators and want to reduce historical emissions of mercury as well, while separators exclusively reduce current emissions.

**Table 8. Costs, benefits and cost-effectiveness of amalgam separators vs decontamination, per facility, over a ten-year period**

| Parameter | Unit | Amalgam separators | Decontamination | |
|---|---|---|---|---|
| | | | Mean | Median |
| Amount of mercury removed | G | 772 | 297 | 105 |
| Value of mercury removed (gross benefit) | $€_{2018}$ | 28 360 | 10 910 | 3 860 |
| Costs | $€_{2018}$ | 10 240 | 5 140 | 5 010 |
| Costs per kg removed mercury | $€_{2018}$ | 13 300 | 17 300 | 47 700 |
| Net benefit | $€_{2018}$ | 18 120 | 5 770 | -1 150 |
| Benefit-to-cost ratio | - | 2.8 | 2.4 | 0.74 |

It seems that the use of amalgam separators and to remove mercury before it enters the pipes generates a higher net benefit to society, rather than to regularly conduct a decontamination procedure and capture mercury accumulated in the pipes. This conclusion indirectly supports the recent decision to oblige all European facilities to install amalgam separators (European Parliament and of the Council 2017/852). However, since removal efficiency of amalgam separators is limited, certain percentage of the mercury will anyway slip through

[13] Screening results and Sweden Recycling AB, personal communication during 2019

[14] Screening of 531 clinics was conducted in the beginning of the project to identify clinics suitable for the project's decontaminations.

a separator and partly adhere to the pipes, accumulating there over the years. One way to tackle this mercury is via decontamination.

#### 3.2.2.2. Potential improvements in amalgam separators' efficiency

The reduction efficiency of an average amalgam separator must be at least 95%, according to the standard ISO 11143[15]. Part of the remaining 5% of mercury could also be captured by separators if they were more efficient. Instead, some of this mercury is accumulating in the pipes and being removed later by means of decontamination. Below, we compare costs and benefits of decontamination with costs and benefits of improved amalgam separators. By "improved" here we mean than a separator removes 99% instead of 95%, i.e. additional 4% currently going to the pipes.

To make such comparison, the same time horizon should be used. Decontamination is made on average once in 10 years, which is why we scale up costs and estimates of amalgam separators to the same period. Investment costs are in this case not annualized but we use the total investment costs (688 Euro/separator) as they are, since an investment of amalgam separator is also expected to last for app. 10 years.

A more efficient separator would mean that parts filled with sludge should be changed more often[16]. We assume that the weight of one full separator is the same as in case it is 95% efficient but the average number of annual changes increases from 1.3 to 1.35.

Increased reduction efficiency of amalgam separators could be achieved by better maintenance, or by technical improvements with subsequent increase of investment costs, or both. We consider these two cases separately, implying that either maintenance costs increase while investment costs remain the same, or vice versa.

**Higher reduction efficiency due to better maintenance**

We assume that better maintenance primarily implies more working time per day. But together with the increased environmental benefits, costs increase as well. Our calculations show that marginal benefits exceed marginal costs only if the additional working time is less than 1.4 minutes per day per separator – otherwise increased removal efficiency does not bring positive net benefits.

If the additional working time for maintenance is between 0.06 and 1.4 minutes per day per separator, the marginal benefit-to-cost ratio is lower than the average ratio for decontamination (2.4). Only if the increased removal efficiency can be achieved by less than 0.4 minutes per day of additional work (per separator), mercury removal by means of amalgam separators results in more benefits per

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[15] ISO 11143 https://www.sis.se/api/document/preview/909960/

[16] This would probably affect the lifetime of a separator, which depends on the number of changes; this is, however, not considered in the analysis

costs than removal of the same additional amount of mercury (4%) by decontamination.

**Higher reduction efficiency due to technical improvements**

We assume that technical improvements would result in higher investment costs. The calculation shows that marginal benefits would exceed marginal costs if the maximum increase of investment costs is 53% – otherwise increased removal efficiency does not bring positive net benefits.

The cost increase between 16% and 53% means that although the marginal benefits from the 95% to 99% change are higher than the marginal costs, the marginal benefit-to-cost ratio is lower than the average ratio for decontamination (2.4). Only if the increased removal efficiency can be achieved by less than 16% increase in the investment costs, mercury removal by means of amalgam separators results in more benefits per costs than removal of the same additional amount of mercury (4%) by decontamination.

**Cost-effectiveness of efficiency increase depending on the current efficiency**

In the calculations above, we assumed that current removal efficiency of amalgam separators is 95%. However, this is according to the laboratory tests, while in the real-life conditions, efficiency can vary from 75% to 95%, according to Jacobsson-Hunt (2007). We have therefore made additional comparisons between amalgam separators and decontamination assuming that current removal efficiency is 85% and 75%. This means, the additional amount of incoming mercury removed with the improved separator is not 4% but 14% and 24%, respectively.

The results are summarized in Table 9. If we assume that current efficiency of a separator is as low as 75%, additional environmental benefits due to increase of removal efficiency are high enough to allow extra maintenance time up to 11 minutes per day per separator, or up to 4 times higher investment costs – in this case, marginal benefits are higher than marginal costs. Compared to decontaminations, amalgam separators bring more benefits per costs in case if the additional maintenance time do not exceed 3.1 minutes per day per separator, or if investment costs do not increase more than by 118%.

**Table 9. Cost-effectiveness of improved amalgam separator's removal efficiency (99%) vs. cost-effectiveness of decontamination**

| Parameter | Current removal efficiency of a separator | | |
|---|---|---|---|
| | **75%** | **85%** | **95%** |
| Annual number of changes for 99% efficient separator | 1.72 | 1.51 | 1.35 |
| **Maximum values of additional maintenance time and maximum investment cost increase to assure that marginal benefits (from removal efficiency increase up to 99%) exceed marginal costs** | | | |
| Maximum additional time for maintenance, min/day | 10.5 | 5.4 | 1.4 |
| Maximum increase of investment costs, % | 406% | 209% | 53% |
| **Maximum values of additional maintenance time and maximum investment cost increase to assure that marginal benefit-to-cost ratio is higher than benefit-to-cost ratio for decontamination (2.4)** | | | |
| Maximum additional time for maintenance, min/day | 3.1 | 1.6 | 0.4 |
| Maximum increase of investment costs, % | 118% | 61% | 16% |

### 3.2.3. Amalgam separators: Sensitivity analysis

Like in the case of decontamination, valuation of environmental effects of mercury discharge is crucial for the CBA results. Using the low-end valuation, one can conclude that amalgam separators does not result in net benefits, while the high-end valuation results in the annual net benefit increase from 650 Euro to 2100 Euro, and the corresponding change of benefit-to-cost ratio from 2.7 to 6.3. This is illustrated in Figure 12 12. The break-even point, where amalgam separator starts bringing positive net benefits, is 13 800 Euro/kg Hg.

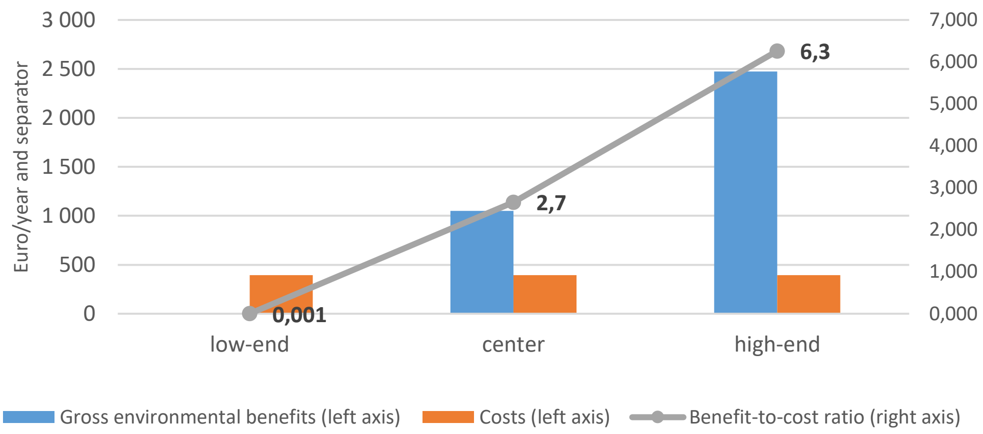


**Figure 12. Costs and benefits of amalgam separators depending on the valuation of mercury effects**

Using high-end valuation would also result in increased general cost-effectiveness of more efficient (99%) amalgam separators. However, the results of the comparisons between a more efficient separator and a decontamination, as alternative ways to treat the mercury not captured in a 95% efficient separator, would be the same as in case the central values are used, since the value of the effects becomes higher for both technologies.

### 3.2.4. Additional benefits from mercury removal at chair-side filters

In addition to decontamination and amalgam separators, mercury is removed from the environment together with the mass captured by chair-side particle filters. Such filters are often installed upstream of amalgam separator and remove larger amalgam particles, assure proper work of amalgam separators. The combined treatment system can achieve removal efficiency over 99% (Fan et al, 2002). It is estimated that the annual amount of mercury removed by the chair-side filter is 8.7 g per clinic[17]. It corresponds to the annual environmental benefit of 320 Euro per clinic.

Figure 13 illustrates environmental benefits resulting from three different ways of mercury removal at dental clinics. To be comparable, the estimates for chair-side filters and amalgam separators are multiplied by ten – the suggested average number of years between two decontaminations. The estimate for amalgam separator is also multiplied by 2.7 – the average number of separators per clinic considered within the project. The resulting amounts of mercury removed by chair-side filter, decontamination and amalgam separators within a ten-year period are 87g, 297 g, and 772 g, respectively.

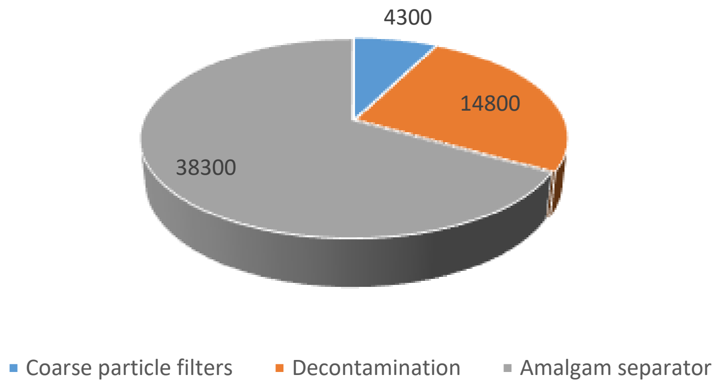


**Figure 13. Environmental benefits resulting from different ways of Hg removal techniques from the environment at dental clinics, Euro/10 years**

Major part of the benefits (67%) is achieved by amalgam separators, while contribution from decontamination is about 26%. It should be remembered that these three ways to remove mercury from clinics cannot be considered as replaceable. First, they target different fractions of mercury: coarse filters tackle mercury bound to large amalgam particles, separators take care of a finer particle fraction, and decontamination is used to remove mercury bind to so small particles that they are not caught by separators, and mercury bound to the particles after it entered the pipes in a dissolved form. Second, the techniques have different legal status: decontamination procedure is not mandatory while amalgam separators should be installed at all facilities in Sweden.

[17] Medentex, personal communication 2019.

## 3.3. Scaling up the results to a European level

To investigate the potential benefits from mercury removals on a regional, European level, we scale up the results of the analysis. The total number of dental clinics in Europe is assumed to be 170 000 (based on the interval presented in BIO Intelligence Service 2012). We assume that in European clinics, like in the Swedish clinics included in the project, the average number of amalgam separators per facility is 2.7. We further assume that the internal costs and valuation of external effects are the same as estimates in the current projects, so that we only scale up the calculated net benefits.

The total net benefits from amalgam separators, if installed in 170 000 clinics, would amount to appr. 300 million Euro (up to 954 million Euro, if the high-end valuation of mercury effects is used). These are the total estimated net benefits for Europe, major part of which is already achieved. BIO Intelligence Service (2012) estimates that about 75% of clinics were equipped with amalgam separators in 2012. Since new legislation entered into force in January 2019, the remaining 25% of the clinics must install amalgam separators as well, which corresponds to 75 million Euro net benefits for society (European Parliament and of the Council 2017/852).

The total net benefits of decontamination, if scaled up to 6 000 clinics (target value for project performance indicators, see Hg-rid project's Final report), is estimated at 35 million Euro (up to 124 million Euro, if the high-end valuation of mercury effects is used).

At the low-end valuation of effects, neither amalgam separators nor decontaminations result in net societal benefits.

## 3.4. Local economy and employment effects

The societal effects in form of health and environmental effects have been addressed in the cost-benefit analysis (Chapters 3.1 and 3.2). In this Chapter, we present the assessment of effects on employment and local economy.

Since the focus of the project has been mainly on developing decontamination methods and increasing the knowledge of how to maintain amalgam separators and handle mercury at the clinics, there has not been an employment effect during the project time.

As described in Chapter 1, regulations on dental amalgam has been in force in Sweden for a long time, this including the ban on its use and the use of amalgam separators. Hence, the project is not expected to significantly affect employment or the local economy. The same is valid for the decontaminations, but for this action there is no mandatory requirement today, and the current requirements vary between municipalities in Sweden. According to a survey by Tobiasson (2017), 9% of municipalities require a decontamination if the clinics are in operation, and 77% when a clinic is about to shut down. Tobiasson (2017) survey also indicates that the interpretation of the legislation differs between the Swedish municipalities, concluding that an increased collaboration between the municipalities, together with national guidelines on mercury handling at dental facilities, would help to harmonize the requirements. To increase the number of performed decontaminations a harmonization of the municipalities' interpretation of (mainly) the Environmental Code is a prerequisite, i.e. if the harmonization would lead to stricter requirements for the clinics. This is due to the lack of incentives for the clinics to otherwise do this today, since the costs are covered by dental clinics, meanwhile it is society in general that takes advantage of the benefits. Hence, there is motivate of the need for regulation due to this market failure. On the other hand, it is important to keep in mind, that our cost-benefit analysis indicates that all decontaminations might not bring societal net benefits.

Based on this the conclusion has been that there is a need for regulation on both decontamination and amalgam separators to reach a large implementation, and hence potential significant effects on employment. Therefore, there is a great potential on the regional level due the new regulation in the EU on the mandatory use of amalgam separators in dental clinics from 1$^{st}$ of January 2019. The potential on increased employment is seen in the manufacturing and sales of amalgam separators, the environmental maintenance service (e.g. installing separators and changing the filters) and in the amalgam waste handling. There have been studies assessing the effects of phasing out amalgam, including the use of amalgam separators, on an EU level (e.g. BIO Intelligence Service 2012; SWD 2016). One of the studies is currently being carried out – "Assessment of the feasibility of phasing out dental amalgam" by Deloitte Sustainability (FR), Wood (UK), INERIS (FR) and REC (HU) - expected to be published in February 2020.

Finally, according to the regulation of the European Parliament and of the Council (2017/852), dental practitioners shall ensure that their amalgam waste is handled and collected by an authorized waste management establishment or undertaking. This is problematic in countries where there is limited infrastructure established for this today, which has been confirmed during the project's participance in several European dental conferences. Hence, there is both a potential and need for such infrastructure to be in place for the clinics to follow the regulations.

## 3.5. Comparison with other studies

In this chapter we present findings in the literature on cost-effectiveness of decontamination of dental clinics and the use of amalgam separators.

**Decontaminations of dental clinics' pipes**

The results from our study gives an estimated cost of 17 300 Euro/kg of mercury removed during decontamination on average. However, there is a large interval between the clinics of 1 700 - 1 208 100 Euro/kg, due to the large range the median can be more representative, i.e. 49 500 Euro/kg. If we look at the total cost per clinic the following costs are obtained: average 5 100 (3 200), median 5000 (2 900), min 2 800 (1 700), max 9 400 (7 100). Numbers in parenthesis are for the decontamination cost, i.e. not including the cost of closing the clinic or cost of receiving the permit for decontamination.

To our knowledge, there is not much written on the cost-effectiveness of decontaminations of dental clinics pipes. We have only found one study, based on decontaminations in Stockholm (Stockholm Vatten 2007). Within that study, 240 decontaminations have been conducted, and the average cost for one private clinic, which is the category closest to the clinics in our analysis, is 2 590 Euro. For larger clinics a cost interval of 6 500 – 13 000 Euro is given, however, it is noticed that the cost varies a lot, and that both higher and lower costs have occurred. In these figures, it is only decontamination cost which is included, not the cost of permit or cost of closing the clinic. Compared to our obtained average costs, they are somewhat lower for similar sized facilities, however, considering a large variation between the clinics in both our study and in Stockholm Vatten (2007), there are overlaps between the presented ranges.

The average cost per removed kg of mercury in Stockholm Vatten (2007) is 920 – 11 300 Euro[18]. These costs from Stockhom Vatten (2007) can be compared with our results only for the decontamination cost, i.e. not including the cost of closing the clinic and cost of receiving the permit. This average is 10 900 Euro/kg, and median 31 400 Euro. Maximum cost is 791 700 and minimum 970 Euro/kg. Hence, our estimate lies within the interval presented in the previous study, close to its high end.

**Amalgam separators**

The results from our study gives an estimate of an annual cost of 400 Euro/clinic for having one amalgam separators installed (an average of 2.7 separators per clinic, assumed in our study, would generate a cost of 1 070 Euro) and 13 800 Euro per kg removed mercury.

These estimates can be compared with other costs we have found in the literature, see Table 10 – but with cautiousness, since the results depend on the assumptions on, among others, number of separators per clinic and amount of Hg removed by a separator. The assumptions are not always clearly explained in the reference studies, but most of them seem to assume one separator per clinic. The removed amount of mercury varies, but since dental amalgam is prohibited to use in Sweden which is not the case in many other countries it can be assumed that the removed amounts of mercury assumed in other studies are higher than in our study. Another important aspect is that none of the cost estimates presented in the tables below includes the cost of amalgam waste treatment – while in our study it is included. Our result of 400 Euro/clinic is in line with the cost range found in the studies, somewhat lower if adding the cost of waste management to the estimate of the costs of installation, maintenance and

[18] Higher cost estimate also includes e.g. project management. See Stockholm Vatten (2007) o. 14. Costs are recalculated to $EURO_{2018}$.

certification presented in BIO Intelligence Service (2012), i.e. 525 – 1 170 Euro/clinic.

**Table 10 Annual costs per clinic for amalgam separator**

| Annual cost per clinic (€2018) | Costs included | Reference |
|---|---|---|
| 420 -530 (assuming 2.1 chairs per clinic) | Installation<br>Maintenance<br>Certification | BIO Intelligence Service (2012) |
| 105 – 640 (assuming 2.1 chairs per clinic) | Waste management | BIO Intelligence Service (2012) |
| 170 – 850 (assuming 4 chairs per clinic) | Purchase<br>Installation<br>Maintenance<br>Replacement of filter | US EPA (2008) |

The costs per kg removed mercury vary a lot in the literature: from 1 620 – 2 080 Euro/kg to 383 500 – 1 412 000 Euro/kg, see Table 11. Our cost estimate of 13 800 Euro/kg mercury lies in between, but closer to COWI and Concorde East/West (2008) estimates. The cost from Vandeven & McGinnis (2005) differs greatly and might be overestimated due to only considering the mercury emissions going to surface water from the wastewater treatment plants. Hence, we are assuming that COWI and Concorde East/West (2008) is more relevant for comparison. The difference in costs per Euro may possibly be explained by lower amounts of removed mercury in Sweden, as mentioned above.

**Table 11 Costs per kg removed Hg by amalgam separators, from literature**

| Cost per kg Hg (€2018) | Costs included | Reference |
|---|---|---|
| 1 620 – 2 080 | Installation<br>Maintenance<br>Certification (indirectly also waste treatment and training of personnel) | COWI and Concorde East/West (2008) |
| 383 500 – 1 413 000[19] | Purchase<br>Installation<br>Operation & Maintenance | Vandeven & McGinnis (2005) |

[19] Estimating cost of removing discharge of mercury form dental facilities to surface waters of the US via wastewater treatment plants of 0.4 ton per year.

# 4. Discussion and conclusions

Within the project, we have estimated benefits and costs of two possible abatement measures to remove mercury from dental care facilities' wastewater – decontaminations (compared to the reference scenario, see Chapter 2) and use of amalgam separators (compared to the hypothetical scenario where amalgam separators are not used). The focus of the project was on decontaminations; the results from 68 decontaminations have been used in the assessment of the socio-economic impacts of this procedure. For amalgam separators, analysis is based on much less detailed data – mainly average values. The main findings for both technologies are summarized in Table 12.

**Table 12 Results of the analyses**

| Technology and time horizon | Range | All 68 decontaminations | One decontamination of a clinic | All amalgam separators at a clinic | One amalgam separator |
|---|---|---|---|---|---|
| | | 10 years | 10 years | 10 years | 1 year |
| Costs of removed Hg, €$_{2018}$/kg | Min | 1 700 | 1 700 | 13 300 | 13 800 |
| | Mean | 17 300 | 17 300 | 13 300 | 13 800 |
| | Max | 1 208 100 | 1 208 100 | 13 300 | 13 800 |
| Net benefits, Euro | Min | -349 200 | -9 400 | -10 100 | -400 |
| | Mean | 392 700 | 5 800 | 18 100 | 660 |
| | Max | 1 399 400 | 199 600 | 56 570 | 2080 |
| Benefit-to-cost ratio | Min | 0.0013 | -0.00004 | 0.0015 | 0.0014 |
| | Mean | 2.1 | 2.4 | 2.8 | 2.7 |
| | Max | 5.0 | 51 | 6.5 | 6.3 |

An **average decontamination** generates a net benefit for society of 5.8 thousand Euro, with a benefit-to-cost ratio of 2.4. However, with a wide range of -9.4 to 200 thousand Euro in net benefit/decontamination, depending on the amount of mercury removed and valuation of effects.

**In total, the 68 decontaminations** performed within the project generated net benefit of 390 thousand Euro, with the benefit-to-cost ratio of 2.1 (with a range of -350 to 1 400 thousand Euro, depending on the monetary value set on mercury's impact). On average, it costs 17 300 Euro to remove 1 kg of mercury by means of decontamination.

For **amalgam separators** the analysis has been conducted per separator, indicating a benefit-to-cost ratio of 2.7 and an annual net benefit to society of 660 Euro (a range of – 400 to 2100 Euro, depending on the monetary value of mercury). The average costs to remove 1 kg of mercury with amalgam separator are 13 300 Euro.

The literature review shows a great variation on cost-effectiveness for amalgam separators, especially the cost per kg, but our results on cost per clinic is in line with studies such as BIO Intelligence Service (2012). The assumptions made in the reviewed studies are not always transparent, hence not completely comparable.

For decontamination, only one other similar study has been conducted to our knowledge. Compared to that study our results are higher, both per kg and per clinic, but they only present mean values but stating that they also seen high variation between clinics just like in our study.

The results of our study can be with a certain cautiousness extrapolated to the **European level**. If decontaminations are performed in additional 6000 clinics in Europe, the total net benefit would amount to 35 million Euro. If 25% of all the clinics in Europe (42 500 is assumed to lack amalgam separators of 170 000), would install separators, this will result in the additional net benefit of 75 million Euro. These estimates are associated with additional uncertainties regarding the total number of clinics in Europe, average number of amalgam separators per clinic, and percentage of amalgam separators already installed before the new regulation entered into force.

A **comparison** between the two considered abatement measures (over a period of 10 years). indicates that the amalgam separator gives a higher benefit-to-cost ratio of 2.8 compared to 2.4 for an average decontamination. Our results, see Table 12 above, indicate that **amalgam separators are more cost-effective than decontamination** in terms of the costs per removed amount of mercury, and that they provide more welfare per invested cost as well. However, it cannot be interpreted in a way that dental facilities do chose one of the technologies depending on their cost-effusiveness and net benefits. Amalgam separators are a mandatory abatement measure in the EU from January 1st, 2019, while decontamination can be considered as an important complimentary measure to remove mercury that cannot be captured by amalgam separators. A part of the mercury – dissolved gaseous mercury fraction – cannot be removed by either of these technologies.

Based on the data, assessments and results presented in the report, there are a few topics in need of discussion.

Our results indicate that both conducting decontaminations and using amalgam separators result in social welfare increase. However, the results depend on amount of mercury removed and on valuation of mercury's impact: if at least one of these values is below a certain break-even point (140 g Hg and 17 300 Euro/kg Hg, respectively), no net benefit is generated.

The range of the removed mercury varies within our project between 3.6 g to 2.4 kg per clinic. The high **variation of mercury removed** during decontaminations brings the largest uncertainties to the project results at the level of dental facilities. The same is also found in the project presented by Stockholm Vatten (2007). Based on that study and our current one it is evident that it is difficult to find strong correlation between any parameters such as age of the clinic, earlier decontamination, pipe length or material, or mercury level in the water samples, with the removed amount of mercury per decontamination. The gradient of the pipes had been discussed and identified as an important parameter, but it has not been feasible to study the effect of this parameter and to confirm this expert judgement due to the lack of quantitative data.

The **monetary valuation** is also an important aspect to discuss. The range of values we used in the study is 23 Euro to 86 500 Euro, with the central value of 36 700 Euro. There are large uncertainties in the environmental and health impacts of mercury. The impact of mercury on people's health is debated within the scientific community; the impact in form of IQ loss is certain but not cardiovascular effects. The inclusion of cardiovascular impact strongly increases the values; in some examples it stands for 90% of the total valuation (Dubourg 2018; BIO Intelligence Service, 2012; ECHA 2010). Furthermore, very few valuation studies on environmental effects have been found.

The results also depend on assumptions made regarding the **pathways** and the ultimate faith of mercury in the environment after it leaves dental facilities with sewage water. In the present analysis, we use the following distribution factors – 35 % to water, 35 % to soil, and 30% to air. In COWI and Concorde West/East (2008) and in Bio Intelligence (2012), different distribution from wastewater treatment plants is assumed: 15-35% to water, 45-60% to soil and, 5 – 15 % to air. This higher share of emissions to soil would increase the valued societal benefits.

In our analysis we focus on the external effects of mercury and $CO_2$, hence, not taking into account other metals included in amalgam such as silver, copper, tin and zinc. If we had included them, the benefit to society would increase. On the other hand, some other negative impacts (such as e.g. air pollution from transport of mercury waste) are not included either, which decreases the benefit.

For **amalgam separators**, another important assumption affecting the results are investment costs. We have chosen one cost estimate, based on the participating company's prices; in other studies, a large cost variation can be found (see COWI 2008; US EPA 2008). Neither do we use a range for mercury uptake by a separator, but an annual average for actually collected mercury at Swedish facilities, which also varies a lot.

Since decontamination is most often a voluntarily performed procedure, it is interesting to discuss what are the main **driving forces and obstacles**, and what can be done to increase the number of decontaminations. A decontamination does not necessarily bring net benefits; when it does, the benefits concern society in general while the costs are paid by the clinics. This gap is in line with the polluter pays principle, there is clearly no economic stimulation for dental facilities to perform decontaminations today. Besides, it can happen that environmental authorities do not approve the procedure. The experience from the project is that it was difficult to find a large enough number of facilities to be decontaminated, even despite a high subsidy of the costs (up to 80%). A more common reason for facilities to voluntarily order decontaminations is in case the pipes are clogged and therefore need a cleaning. Otherwise, it could be a requirement by a supervising authority (in the case for Sweden, the municipality) on a final decontamination when a facility is being shut down. Thus, to increase the number of decontaminations, an important factor is municipalities' requirements on dental facilities – which today differs between municipalities due to different interpretation of environmental legislation, mainly, the Environmental code.

On **the EU level**, discharge of mercury to wastewater from dental facilities is expected to be decreasing in the coming years, due to larger number of amalgam separators installed after January 1st, 2019. Trends for decontaminations are harder to predict due to the missing regulation on that issue. The common problem for both measures though is seemingly underdeveloped infrastructure for handling mercury-containing waste. Not in all European countries the whole logistics chain of waste transport and proper handling is in place, which poses difficulties in following the legislative requirements by dental clinics. Building an efficient system for mercury waste handling and final disposal would not only decrease mercury discharge but also provide job opportunities enhancing the local and regional market.

Considering uncertainties in the results on the benefits-cost ratio and cost-efficiency of the considered mercury abatement options, due to high variation in valuation of benefits and removed amounts of mercury, we would highlight that more studies are needed, especially regarding decontamination, which seems to be an under-researched area compared to amalgam separators. This is to verify the findings from our study.

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# ANNEX 1

## Valuation studies of mercury impacts

Table 13 below shows an overview of the screened studies on valuation on mercury impacts on health and ecosystems, as well as abatement cost. Full references are to be found in the References.

## Table 13 List of valuation studies of mercury effects

| Reference | Type of publication | Type of valuation | To which element | Value and unit | Comment |
|---|---|---|---|---|---|
| Steen 2015 | Report | Depletion of resource | Soil | 54 298 EUR/kg hg | Depletion of mercury reserves |
| Steen 2015 | Report | Damage cost | Water | 20.3 EUR/kg hg | Health effects (intellectual disability) |
| Steen 2015 | Report | Damage cost | Air | 20.3 EUR/kg hg | Health effects (intellectual disability) |
| Anthesisenveco 2017 | Report | Damage cost | Soil | 262 - 64 760 SEK/kg hg | Health effects (toxicity) |
| Ahlroth 2007 | Report | Damage cost (WTP) | All | 54 000 SEK/kg hg | WTP for health and effects on crops. |
| Ahlroth 2009 | Report | Damage cost (DALY) | All | 72 000 SEK/kg hg | Based on Friedrich (2007) |
| ECON Energi 1995 | Report | Various | All | 1 315 NOK/g Hg (Damage cost - VSL); 20.5 NOK/g Hg (Abatement), 2016 NOK/g Hg (Resource depletion) | Damage cost - health effects |
| Friedrich 2007 | Report | Damage cost (DALY) | All | 8 000 EUR/kg hg | Health effects |
| Johansson 1999 | Report | Damage cost (Shadow price) | Air | 7000 SEK/kg hg | Health effects (human toxicity) |
| Johansson 1999 | Report | Damage cost (Shadow price) | Soil | 74 000 SEK/kg hg | Health effects (human toxicity) |
| Johansson 1999 | Report | Damage cost (Shadow price) | Water | 7 100 SEK/kg hg | Health effects (human toxicity) |
| Johansson 1999 | Report | Damage cost (Shadow price) | Air | 28 000 - 54 000 SEK/kg hg | Aquatic toxicity |
| Johansson 1999 | Report | Damage cost (Shadow price) | Soil | 75 000 SEK/kg hg | Aquatic toxicity |
| Johansson 1999 | Report | Damage cost (Shadow price) | Water | 5000 SEK/kg hg | Aquatic toxicity (freshwater and marine) |
| BIO Intelligence Service 2012 | EU-report | Various | Air | 5000 - 20 000 EUR/kg Hg (Max. 250 000EUR/kg) | |
| Dubourg 2018 | Report | Various | All | 8 800 - 24 700 USD/IQ point<br>1 500 - 214 486 USD/kg hg | Various |
| Giang and Selin 2015 | Scientific paper | Damage cost (VSL) | Air | 9 936 USD/IQ point | Non-fatal myocardial infarction: 120 953 USD, Fatal, actue, myocardial infarction: 6.3 million USD. |
| Bellanger et al 2013 | Scientific paper | Damage cost | | 13 579 EUR/IQ point | Reduced lifetime income |
| Sundseth et al 2010 | Scientific paper | Damage costs | Air | 3 000 - 22 300 USD/IQ point<br>18 000 USD as worldwide average.<br>Their assumptions gives: 1500 USD/kg hg | Cost: loss of earnings, loss of education and opportunity co |
| Rice and Hammitt 2005 | Report | Damage cost (WTP/VSL) | Air | 3 900 USD/ton hg - 194 500 USD/kg hg | |
| Vandeven and McGinnis 2005 | Scientific paper | Abatement costs | Water | 380 million - 1.14 billion USD/ton hg | Amalgam separators |
| Hylander and Goodsite 2006 | Scientific paper | Abatement costs | All | 8 726 - 21 815 EUR/kg hg | Removing sediment in lakes |
| ECHA 2010 | Report | Abatement costs<br>Damage cost (WTP) | Air | 10 000 EUR/kg hg (20 - 1 300 000 USD/kg hg)<br>(5 000 - 250 000EUR/kg hg: health effects) | Various |

# ANNEX 2

## Estimation of minimum and maximum values of mercury's health impacts

| **Individual preferences** | | | **Value per kg hg** | | | **Weighting** | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| | | | Air | Soil | Water | Air | Soil | Water | |
| Air-Low | Soil-low | Water-low | 20 | 28 | 20 | 0.3 | 0.35 | 0.35 | 23 |
| Air-Low | Soil-low | Water-high | 20 | 28 | 20 | 0.3 | 0.35 | 0.35 | 23 |
| Air-Low | Soil-high | Water-low | 20 | 6 850 | 20 | 0.3 | 0.35 | 0.35 | 2 411 |
| Air-Low | Soil-high | Water-high | 20 | 6 850 | 20 | 0.3 | 0.35 | 0.35 | 2 411 |
| Air-High | Soil-low | Water-low | 280 400 | 28 | 20 | 0.3 | 0.35 | 0.35 | 84 137 |
| Air-High | Soil-low | Water-high | 280 400 | 28 | 20 | 0.3 | 0.35 | 0.35 | 84 137 |
| Air-High | Soil-high | Water-low | 280 400 | 6 850 | 20 | 0.3 | 0.35 | 0.35 | 86 525 |
| Air-High | Soil-high | Water-high | 280 400 | 6 850 | 20 | 0.3 | 0.35 | 0.35 | 86 525 |
| | | | | | | | | **Min** | 23 |
| | | | | | | | | **Mean** | 43 274 |
| | | | | | | | | **Median** | 43 274 |
| | | | | | | | | **Max** | 86 525 |

References for the table above are as follows, valuations based on willingness-to-pay:

Air-low: Rice and Hammitt (2005)

Air-high: Rice and Hammitt (2005)

Soil-low: Anthesisenveco (2017)

Soil-high: Anthesisenveco (2017)

Water-low: Steen (2015)[20]

Water-high: Steen (2015)

[20] Due to lack of more references found on individual preference valuation on mercury release to water, the same value has been used for high and low valuations.

# ANNEX 3

## Evaluation of decontamination effects via mercury concentrations in wastewater

The purpose of the decontamination is to decrease amount of mercury leaking from the pipes into environment via wastewater. Mercury concentrations in wastewater before and after decontamination can thus be considered as a criterion for the procedure's efficiency. Here, we make an attempt to estimate annual environmental benefits via available data on mercury concentrations in the wastewater before and after decontaminations. The test results are associated with large uncertainties, according to Sweden Recycling AB – those are, however, not quantified. The results of this side-analysis should therefore be interpreted with cautiousness.

It is important to take into consideration how fast after a decontamination water samples are collected. Shortly after the procedure, mercury concentrations might by elevated in comparison to the situation before, because the decontamination flushes away the biological skin or sediment that previous prevented some of the mercury from leaking (Stockholm Vatten 2007).

After a while, mercury concentrations stabilize, and should in general become lower than concentrations before decontamination.

Data on mercury concentrations in the water both before and after decontamination are only available for a limited number of facilities: 33 out of 68. The available numbers are illustrated in Figure 14.

In 8 of 33 facilities, concentrations of mercury in the water after decontamination seem to increase (the range is from 35% to 1884%). Not all these samples are taken shortly after decontamination (0.5-2 months): one is taken 9 months after, and one 19 months after. At the same time, there are several clinics where decreased mercury concentrations are observed in samples taken shortly after decontamination. It is thus hard to make conclusions regarding the effects of time between a decontamination and a water sample after, on the observed difference in the concentrations.

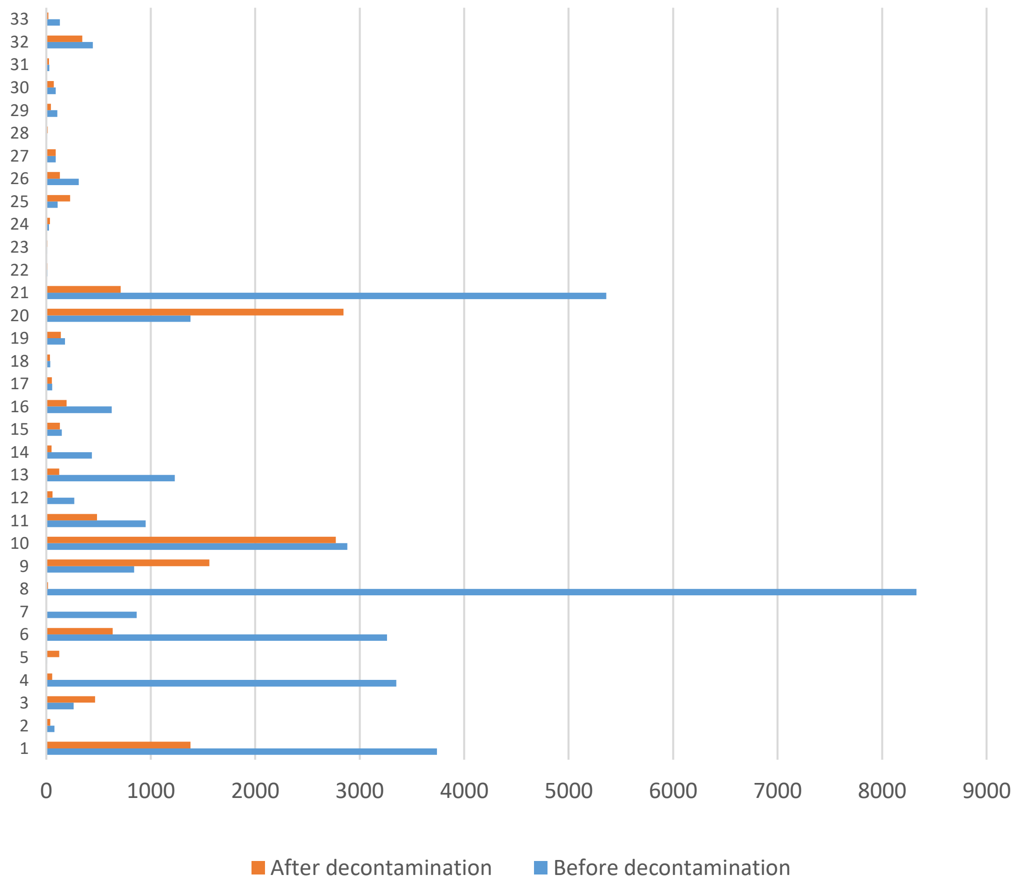


**Figure 14. Mercury in wastewater samples before and after decontaminations, µg/l**

One of the projects' measurable objectives is 50% reduction of mercury concentrations in the wastewater from dental clinics with the initial concentration above 1000 µg/l. The available data for the 8 clinics where this applied imply that this objective was achieved for major part of the facilities, see Figure 15. At one of these facilities, mercury levels increase.

Within the additional analysis of health and environmental benefits from decontamination, we have estimated amounts of mercury, annually removed from wastewater, via differences in concentrations shown in Figure 14. Then, we calculated corresponding annual reductions of external costs (gross benefits). The following assumptions have been used for this calculation:

- Wastewater discharge – 40 liter/day and per dental chair;
- 230 working days per year.

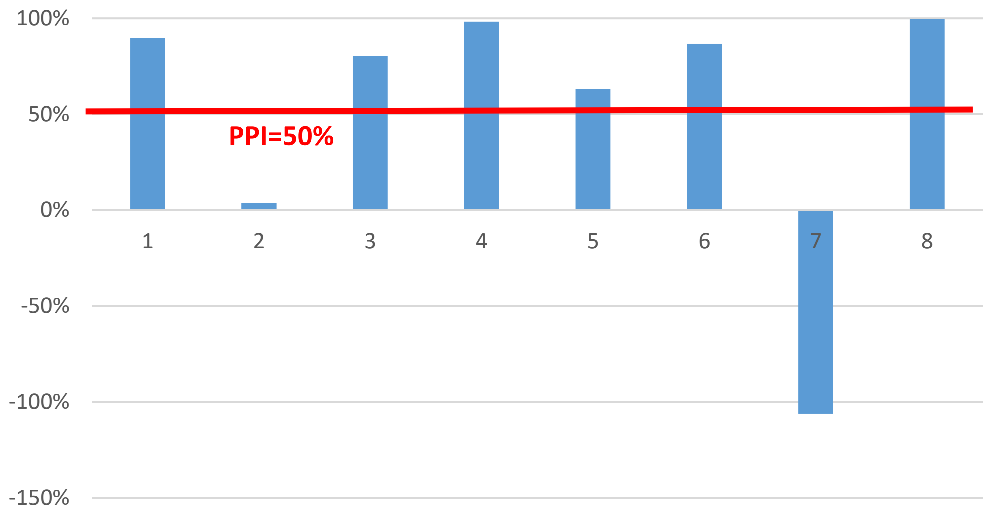


**Figure 15. Reduction of mercury concentrations in wastewater after decontamination at facilities with initial mercury concentrations above 1000 µg/l**

The total annual discharge is thus 9 200 liter per year and chair. Applying this number to clinics where mercury concentration in the wastewater decreases after decontamination, we calculate avoided amounts of mercury that would have entered the wastewater flow in case decontamination was not performed. The results are presented in Table 14.

**Table 14. Annual discharge of mercury into wastewater, avoided amounts due to decontamination, and corresponding environmental benefits**

| N | Chairs | Hg concentration, µg/l | | Amount of mercury, g | | |
|---|---|---|---|---|---|---|
| | | Before | After | To water before decontamination, annually /chair | Avoided, to water, annually /clinic | Collected during decontamination/clinic |
| 1 | 2 | 3740 | 1380 | 69.9 | 43 | 55 |
| 2 | 2 | 77.9 | 38 | 12.6 | 0.7 | 695 |
| 3 | 6 | 37.9 | 34.3 | 4.7 | 0.2 | 47 |
| 4 | 4 | 3350 | 56.5 | 127.6 | 121 | 157 |
| 5 | 3 | 626 | 195 | 21.4 | 11.90 | 225 |
| 6 | 3 | 3260 | 636 | 93.3 | 72 | 94 |
| 7 | 3 | 865 | 5.0 | 34.3 | 24 | 906 |
| 8 | 2 | 8330 | 17 | 340.8 | 153 | 1688 |
| 9 | 6 | 2880 | 2770 | 172.4 | 6 | 242 |
| 10 | 4 | 950 | 486 | 35.8 | 17 | 18 |
| 11 | 2 | 268 | 58.6 | 19.1 | 4 | 284 |
| 12 | 4 | 1230 | 125 | 55.7 | 41 | 262 |
| 13 | 5 | 437 | 50.9 | 20.9 | 18 | 40 |
| 14 | 4 | 149 | 131 | 5.8 | 1 | 13 |

<table>
<tr><th rowspan="2">N</th><th rowspan="2">Chairs</th><th colspan="2">Hg concentration, µg/l</th><th colspan="3">Amount of mercury, g</th></tr>
<tr><th>Before</th><th>After</th><th>To water before decontamination, annually /chair</th><th>Avoided, to water, annually /clinic</th><th>Collected during decontamination/clinic</th></tr>
<tr><td>15</td><td>5</td><td>56.9</td><td>52</td><td>3.9</td><td>0.2</td><td>45</td></tr>
<tr><td>16</td><td>4</td><td>180</td><td>138</td><td>9.2</td><td>1.5</td><td>117</td></tr>
<tr><td>17</td><td>6</td><td>11.1</td><td>10.6</td><td>10.0</td><td>0.0</td><td>207</td></tr>
<tr><td>18</td><td>5</td><td>311</td><td>131</td><td>16.9</td><td>8.3</td><td>45</td></tr>
<tr><td>19</td><td>2</td><td>444</td><td>344</td><td>9.7</td><td>1.8</td><td>62</td></tr>
<tr><td>20</td><td>5</td><td>5360</td><td>712</td><td>249.1</td><td>214</td><td>23</td></tr>
<tr><td colspan="5">Avoided annual Hg discharge/clinic</td><td>738 g</td><td></td></tr>
<tr><td colspan="5">Annual environmental benefit/clinic</td><td>27 100 Euro</td><td></td></tr>
</table>

Calculation based on the data for 20 facilities above results in 13.4 g annual average mercury discharge per chair before decontamination. This number can be compared to 14.5 g per chair annually estimated by Hylander and Goodsite (2006), and to the estimates in Jacobson-Hunt (2007) of 9 g (range 2.6 – 22 g) per chair per year at facilities with amalgam separators.

The average annual avoided amount of mercury per clinic is estimated at app. 738 g, corresponding to the gross environmental benefit of app. 27.1 thousand Euro.

For the same facilities, the average amount of mercury collected during decontamination is 261 g. This amount has been accumulating in the pipes for years, since the beginning of the dental clinic practice in a building, or since the last decontamination/pipes change. Assuming that more or less the same amount accumulates in the pipes annually (a necessary simplification), knowing for how many years the process was going on and knowing the removal efficiency of amalgam separators, we can roughly estimate distribution of the incoming mercury[21] between the part captured by amalgam separators, the part going to the wastewater without being trapped in the pipe system (dissolved gaseous mercury), and the part adhering to the pipes and later decontaminated. The example of such calculation (for facility 1 from Table 14) is as follows:

1. Facility started in 1965, decontamination performed in 2017 – the accumulation period is 52 years.
2. From 55 g Hg collected during decontamination, the annually accumulated amount is 55 g/52 years = 1.1 g/year.

[21] By “incoming mercury” here we mean mercury remaining after a chair-side particle filter upstream of amalgam separator, which also removed part of the mercury containing dental amalgam.

3. Concentration of Hg before decontamination was 3740 µg/l meaning that annual discharge of Hg into wastewater was about 3740 µg/l x 2 chairs x 9200 liter/chair-year = 68.8 g/year.
4. The total annual amount of Hg entering wastewater after an amalgam separator is (68.8 g + 1.1 g)/year = 69.9 g/year.
5. Assuming that removal efficiency of an amalgam separator is 95%[22], it would correspond to the total annual incoming Hg flow of 69.9 g/year*100%/ (100%-95%) = 1397.4 g/year.
6. From which 1.1. g accumulated in the pipes correspond to 0.08%, and 68.8 g passing the pipes without accumulation – to 4.92%.

For all the facilities where we see mercury concentration decrease, we estimate that, on average, 1.1% of the incoming mercury is accumulated in the pipes, while about 3.9% is going to the water. Only part of these 3.9% mercury could be captured by amalgam separators if their removal efficiency was higher than 95%: dissolved gaseous mercury is not bound to particles and thus would not be affected anyway.

The actual removal efficiency of amalgam separators depends on factors such as maintenance and might be lower than 95%. The range estimated in the literature is 75-95% (Jacobsson-Hunt 2007; BIO Intelligence Service 2012). If we assume that the removal efficiency is about 70%, the resulting distribution of the remaining mercury is as follows: 6.5% is accumulated in the pipes and 23.5% is going to the wastewater.

This calculation of mercury distribution is rather simplified since it does not take into account actual complex chemical and physical processes happening in the wastewater. During these processes, mercury can change form and subsequently its “behavior” regarding accumulation and pass-through. Besides, accumulation does probably not happen so gradually as assumed here, especially considering the fact that the use of amalgam separators was not encouraged before the agreement from 1979, and thus much more mercury was annually discharged to the water before 1979 than after amalgam separators became a normal practice.

[22] 95% is the required efficiently of a certified amalgam separator according to the standard ISO 11143 https://www.sis.se/api/document/preview/909960/.