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Multi-criteria evaluation of Emission Control Strategies (ECSs) in case cities

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Abstract

This is the final task conducted within the WP 2: Analysis of case studies of the Source Control Options for Reducing Emissions of Priority Pollutants (SCOREPP) project. The report evaluates emission control strategies (ECSs) proposed in task 2.4, 'Identification of appropriate emission control strategies (ECSs) in case cities', in two of the ScorePP case cities. The short duration and limited budget allocated to this project did not allow the process of implementing proposed ECSs and evaluating their impact based on monitoring. As a result, evaluations were performed in a theoretical manner. Several evaluation matrices were developed in the scope of the project. For example, Task 4.5 evaluates emission control options for individual sources, Task 5.6 evaluates a range of treatment technologies and task 9.7 evaluatesvarious emission control strategies in semi hypothetical case cities (a concept developed in task 9.6). Several evaluations matrices are used in this report to evaluate ECSs. On one hand the matrices developed in tasks 4.5 and 5.6 were used together to evaluate the combination of emission control options and on the other hand the multi-criteria matrix developed in task 9.7 was used to evaluate the emission control strategies (combinations of individual measures). Under both approaches evaluated, tertiary wastewater treatment was identified as the most convenient ECS for city A. Considering the same substance, DEHP, for city B, stormwater treatment was evaluated to be the most convenient ECS to apply. One reason for the difference between the two cities is a higher calculated cost for adding a tertiary treatment at the WWTP in city B because of using different references for calculating costs. A second reason is that first flush is taken care of at the WWTP in city A, and a third reason is that in city B outdoor sources were considered more important than in city A.

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1 Aim and outline

The Source Control Option for Reducing Emissions of Priority Pollutants (ScorePP) project aims at proposing emission control strategies that municipalities, industries and water agencies can apply to reduce emissions of priority pollutants in cities. The project is divided into 9 Work Packages (WPs) that each answer to a specific objective by producing deliverables. This is the last deliverable of WP2 case cities analysis. Work Package 2 (WP 2) aims to obtain information on the occurrence of priority pollutants (PPs) in selected European case cities, to measure PP concentrations within the cities, and to propose source control options tailored to the activities identified as discharging them into urban water. The following work has been achieved to answer WP 2's objectives:

(i) Acquiring information on the PPs present in four different case cities (Task 2.1 Baseline studies in case cities);

(ii) Making a list of relevant PPs identified for monitoring in the 4 case cities, based on a decision tree model (Task 2.2 Identification of PPs for further work in case studies);

(iii) Monitoring campaigns on sludge as well as influent and effluent streams of different wastewater treatment plants (WWTPs) in four European case cities; when possible, monitoring campaigns were conducted in surface water and sediments (Task 2.3: Improved monitoring in case cities) in four case cities;

(iv) Proposing Emission control strategies (ECSs) for PPs found in the WWTP effluent, sludge and surface water from each case city (Task 2.4: Identification of appropriate emission control strategies (ECSs) in 2 case cities); and

(v) Conducting Substance flow analysis (SFA) for selected PPs in case cities (Task 2.5: Substance flow analysis for selected PPs in 2 case cities).

Task 2.4 and 2.5 focused on two cities due to good data availability, continuous cooperation and information exchange with the municipalities and water representatives. Half of the initially included case cities were excluded because information regarding priority pollutants uses, releases and environmental concentrations were limited or unavailable.

This report presents the final task of WP 2, 'Evaluation of identified emission control strategies (ECSs)'. The intention was to evaluate the efficiency of the proposed ECSs using data on the two cities from Tasks 2.4 and 2.5 by comparing PP discharges before and after implementation, using socio-economic and multi-criteria comparisons in accordance with work conducted in WP 8 and WP 9. Time would not allow a full and complete comparison to be conducted on both cities based on monitoring so a theoretical approach to this evaluation was adopted.

2 Method for the evaluation of emission control options and strategies – including limitations and assumptions

2.1 Perspectives to use when evaluating emission control strategies

Several criteria are relevant to the assessment of an ECS but the choice and weight of criteria depend on the evaluator's point of view. The challenge in this task was to assess which perspective to adopt to evaluate an ECS. It was not possible to address all potential perspectives as data was missing for some basic elements (e.g. economic and social aspects at the municipal and regional levels) so the appropriate evaluation measures could not be scored in all cases and could therefore not be included.

The perspective chosen for the evaluation procedure was based on work achieved in previous tasks (deliverable 4.5 and deliverable 5.6), which evaluated emission control options by investigating their performance, their costs, their efficiencies and their environmental impacts. ECSs proposed in both cities included the following options: technological treatment (for municipal WWTP and PP-specific stormwater treatment), substitution (chemical substances and objects) and voluntary initiatives, e.g., some example to be added here. Voluntary initiatives are seen as any non-legislative arrangements aimed at reducing PP emissions into the environment. Voluntary initiatives in this report are applied at the consumer level through programmes initiated by the municipality or by environmental associations, or through actions to increase awareness on PP emissions and the potential for their reduction. No evaluation was done at the industrial level because insufficient data was provided by the relevant industries for case city A regarding the products or processes responsible, the quantities of pollutants involved, and the emission pathways. Furthermore, no PP-emitting industries were identified for case city B. The evaluations of ECSs are done from the perspective of a wastewater treatment plant owner so the evaluation measures are strongly related to the use, performance and maintenance of wastewater treatment plant technologies. The evaluations of chemical substitution (chemical substitution is to replace one particular substance with another substance in a certain product) and voluntary initiatives were also attempted but a generic approach was adopted due to a lack of city specific data. Information linked to practicability and specific costs for specific substitution and voluntary initiative options was not available and no similar studies were found so it was not possible to estimate the costs for these options. A financial appreciation was attempted however, using the evaluation matrix for both ECSs but these are presented as estimations. It is acknowledged that investments are needed but their extent could not be precisely defined. In addition, good ecological, chemical and biological status are to be achieved by 2020 for all water bodies within the EU, therefore ECSs are evaluated with a 10 year horizon, i.e. 10 years after the current date.

2.1.1 Definition of emission control options and emission control strategies

An emission control option is a measure adopted to limit and/or reduce the release and/or discharge of priority pollutants in an urban area. For example, proposing to dentist amalgam disposers to avoid releasing mercury in the sewer network could be seen as an emission control option. An emission control option is specific to a particular source for a priority pollutant in the case of this task. There are different types of emission control options however only chemical substitutions, wastewater treatment options, stormwater treatment options and voluntary initiatives are used for this task. Emission control strategies are sets of emission control options applied to reduce emissions of priority pollutants at an urban scale. In other words, for each source of priority pollutant, an emission control option is proposed. As a result, different combinations of emission control can be used to form alternative emission control strategies. In task 2.4, a short baseline study was done to assess the case city political and social situation. It was noticed that involvement of the municipality regarding the improvement of stormwater and wastewater quality were important aims (based on the budget of the 4 past years), and that further voluntary campaigns were adopted to sensitize the public in relation to pollution issues. Consequently, it was decided to have three types of emission control strategies as these seemed to be the preferred mode of action in 2 of the ScorePP case cities. Emission control strategies assessed are as follows: tertiary treatment of municipal wastewater, stormwater treatment and the voluntary initiatives.

2.2 Baseline situation in cities

Due to incomplete data sets, several assumptions were made to evaluate emission control strategies (ECSs) for different sources within the cities. First, only sources for which existing information had been found were dealt with. Possibilities are that other sources in both cities were identified but due to lack of data those were not taken into account. Second, among the sources for which information had been found, only the main PP sources were used as it was assumed that including the ECS for less important/less polluting/smaller sources would not create a big impact on the overall PPs reduction. Third, only sources that could emit PPs into the water compartment (directly or indirectly) were chosen. Indeed, the aim of the ScorePP project was to decrease PPs emissions into urban water (surface, storm- and wastewater). Fourth, sources that required significant technological and financial investment were not considered as the aim was to propose efficient and realistic ECSs to case cities under current local conditions. When conducting the ECS evaluations, the actual context of the city was considered. For example, the existing socio-economical context was an important fact in order to assess the likelihood of success of the proposed emission control options. The context relied on 2008-2009 perspectives.

Work achieved in task 2.4 identified a range of appropriate city-specific emission control options at the legislative, technological and voluntary initiative level. For both cities, it was decided not to look into further details for legislative means to reduce PPs in cities. The main reasons were that the knowledge on the making and application (cost, time application, local administration) of legislative text was not known (at the regional or local level), help from municipalities was not possible within the project timeframe and data on similar problems was not found. Technological preferences were identified in a previous report based on an understanding of the cities' land use, engagement in environmental issues (especially dealing with water treatment) and existing annual budget to manage the city. As mentioned in deliverable 2.5, the different industries did not provide information about the industrial processes responsible for emitting PPs and therefore industrial treatment options could not be taken into consideration when proposing appropriate ECSs for the case cities. Treatment options therefore only focused on municipal wastewater treatment and stormwater treatment options (specific to one source or one activity).

2.3 Criteria and the scoring methodology

The results of the evaluation of ECSs strongly depend on the type of criteria and stakeholders interested in the outcomes. Evaluation matrices should be seen as support systems to help stakeholders to choose an appropriate ECS to reduce the release of given PPs into the urban area. Different perspectives can be used when making evaluation matrices; this can for example be 1) source specific for a given PP, 2) specific to the combination of PPs within the urban area, 3) according to the urban area's typology, etc. Different evaluation matrices were developed during the ScorePP project; in WP4 an evaluation matrix on assessing the strategies for limiting release for individual compounds was developed, which relied on seven criteria each of them being scored either 1, 2 or 3. In WP5 the evaluation matrix consisted of four criteria, also scored 1, 2 or 3. In WP9, an evaluation matrix was produced using a multi criteria assessment of ECSs for semi-hypothetical case city archetypes. The matrices concerned with WP4 and 5 were intended to assess the potential removal efficiency of a certain emission control option, whereas the method in WP9 aimed at performing a multi-criteria assessment to evaluate a given combination of emission control options. The two first mentioned matrices evaluate the emission control option at the source for a specific PP while the work conducted within task 9.7 aims to evaluate the combination of evaluation options for different PPs from different sources.

2.3.1 Criteria and scoring for Emission Control Options (ECOs)

The evaluation of individual ECO suggested for inclusion in the ECSs proposed in both case cities (Seriki et al., 2009) was done based on criteria identified during ScorePP's 2nd Advisory Board meeting. A scoring matrix was developed in deliverable 4.5 for a broad evaluation of the ECSs (Table 1) (Lecloux, 2008). A second evaluation matrix with its own specific scoring details was proposed for the evaluation of wastewater and stormwater treatment technologies (Ragatt et al., 2009).

Table 1: Evaluation criteria and scoring system of an emission control option

	Score 1	Score 2	Score 3
Technical feasibility	Not feasible	Could be feasible or implemented in less than 10 years	Already feasible
Technical efficiency	Will lead to a low reduction of emission	Could lead to some reduction of emissions	Could lead to a significant reduction of emissions
Probability of reaching the Water Framework Directive (WFD) target	Probability to exceed the WFD targets	Medium probability to reach the WFD targets	High probability to reach the WFD targets[#]
Operational costs	Investment needed is high compare to turn over	Limited new operational costs are needed	No new operational costs are needed
Investment costs	Investment needed is high compare to turn over	Investment needed is low compared to turn over	No investment is needed
Impact on the supply chain	The use could be suppressed	Downstream users should adapt their use	Downstream users will not be affected
Impact on employment	An important negative impact on employment is foreseen	A negligible or limited negative impact on employment is foreseen	An employment increase is foreseen
Impact on drinking water production from surface water*	No effect on drinking water production	Limited positive effects on drinking water production	Large positive effect on the drinking water production
Delay of implementation	Need a very long delay of implementation	Need 2 to 3 years delay to be implemented	Can be implemented in a short time frame

* The criterion should not be taken into consideration in any of the case of both case cities; in city A water is taken from another surface water and in city B the water is taken upstream of the city; [#]: Cessation/negligible load for priority hazardous substances (PHS) or below environmental quality standards (EQS) for priority substances (PS).

The first evaluation matrix (table 1) was used for activities/objects identified as important PP sources using the quantitative data calculated in deliverable 2.5. The second matrix (table 2) was solely used for wastewater treatment technology (Ragatt et al, 2009). Treatment options proposed in the matrix developed in deliverable 4.5 evaluate the possibility of using the municipal wastewater treatment plant as an emission control option for a known source. The evaluation of emission control options for identified sources is based on the criteria and scoring system presented in Table 1, where emission control options with the highest scores are the best performing in relation to the criteria specified. The evaluation of the treatment options in the matrix developed in Task 5.6 is more detailed and uses WWTP influent data. In this case the evaluation is not source-specific, being intended for the combination of different sources entering the WWTP rather than a single source. Municipal WWTPs collect and treat wastewater for different sources including domestic, industrial and stormwater run-off. Deliverable 2.3 showed that WWTPs emit certain PPs in the effluent stream, which suggests that the WWTP technology does not perform efficiently enough to meet required standards. Technological solutions that are applicable to municipal WWTPs were suggested to reduce PPs in WWTP effluent. There is a number of end-of-pipe technologies that treat wastewater on-site in use or under development. Deliverable 5.6 evaluated the feasibility of treatment options using information and data from published literature no more than a decade old. The scoring matrix used to evaluate them was more precise than the scoring matrix of deliverable 4.5 because it had quantified the evaluation criteria. The criteria used were the following (Raggatt et. al, 2009):

1. **Technical feasibility** : score 1 technology not known to exist for given PP, score 2 technology under development for a given PP, score 3 technology available-targeted removal of a specific PP or non-specific removal
2. **The technical efficiency**: Score 1 < 70 % removal efficiency, score 2 70-90 % removal efficiency and score 3 > 90 % removal efficiency
3. **Financial consideration:** The scoring is displayed in Table 2**.**

Table 2 : Scoring for financial consideration of end of pipe treatment (Raggatt et al., 2009)

	Score	**Industrial treatment costs (€/m^3)**	**BMP* costs (€/m^3, €/m^2, or €/m)**	**BMP* costs (€)**
Investment costs	1	>1.0	>500	>25000
	2	>0.1 – 1.0	> 50 – 500	>5000 – 25000
	3	<0.1	<50	<5000
Operation and maintenance costs	1	>2.0	>20	>500
	2	>0.2 – 2.0	>2-20	>100 - 500
	3	>0.2	<2	<100

*BMP, Best Management Practice is in this report used in relation to stormwater treatment, and stands for different kinds of structural stormwater BMPs.[1]

4. **Environmental impact** for municipal wastewater treatment plants and stormwater: Score 1: ≥ 25 × dilution, score 2 : ≤ 6 to 25 × dilution, score 3: ≤ 5 × dilution

For both scoring matrices a high score value is “better” than a low score value.

2.3.2 Criteria and scoring for Emission Control Strategies

The multi-criteria assessment matrix was developed in collaboration with potential stakeholders in task 9.7. Sensitivity analysis for scoring and weightings were done for different criteria to reflect the uncertainties connected with the use of a multi-criteria assessment for city B. The multi-criteria assessment evaluates an ECS, in other words a set of reduction options belonging to a specific category, to apply in order to reduce the emissions of PPs. Unlike the precedent matrices, these assessments give the opportunity to compare different strategies to be used to reduce different PPs from different sources across the urban area. Criteria used in the matrix were as follow (Scholes, 2010):

1. **Feasibility**: is the potential to use a given set of ECSs. Scores are as follow score 1 the technology is not available, score 2 the technology is under development, score 3 the technology is available.

[1] This covers all management techniques that are put in place to remove PPs after they have been manufactured, used or consumed, and after they have been released into the environment by any means described in Directive 2006/166/EC. The treatment options included in this category are the structural stormwater BMPs as well as non-structural BMPs such as street sweeping and dredging of contaminated sediments. (Eriksson et al., 2009). In this report only structural stormwater BMPs are considered

2. **Technical efficiency**: is the assumed reduction of PPs to expect when applying an ECS. Scores are as follow score 1 technical efficiencies below 70 %, score 2 technical efficiencies are between 70 % and 85 %, score 3 technical efficiencies of and above 85 %,
3. **Financial consideration**: is the necessary operational and maintenance costs to take into consideration while applying a given score 1, an amount above 1000M€ needs to be spent score 2 an amount between 100M € and 1000M€ needs to be spent score 3 an amount below 100 M€ needs to be spent
4. **Environmental impacts**: score 1 no reduction of PPs discharge into surface water is foreseen score 2 possible reduction of PPs discharge into surface water is foreseen score 3 reduction of PPs discharge into surface water is foreseen.

Each criterion can also be assigned a given weighting factor depending on the importance the city gives to such criterion. The matrix was developed to evaluate different ECSs proposed in semi-hypothetical case cities archetypes developed in WP9. Three ECSs were evaluated using the multi-criteria evaluation matrix for case cities A and B:

1. Voluntary initiatives,
2. Advanced WWTP processes,
3. Stormwater treatment.

For case cities A and B the ranges for criteria "Technical efficiency" in % were evaluated qualitatively to compare different ECSs as the actual values were not available and could not be generated within the project. Values for this criterion were modified based on the wastewater treatment plant performance on global parameters removals (Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), nitrogen and phosphate). Values for the criterion financial consideration were modified based on the cities' actual annual budget, investments and expenses to reflect as closely as possible the local situation in both case cities.

2.3.3 Criteria and scoring for Emission Control Strategies

Steps conducted to evaluate emission control strategies in city A are as follow:

1) The evaluation of Emission Control Options (ECO) for individual sources,

2) The Evaluation of Combinations of Emission of Control Options (ECECO),

3) The evaluation of ECSs using the multi-criteria evaluation matrix will be done,

4) And last, the outcomes using ECECO and the multi-criteria evaluation matrix will be compared.

For case city B, only the multi-criteria analysis matrix will be used to evaluate the ECSs. The last section will compare outcomes found for both cities for the DEHP (Di(2-ethylhexyl)phthalate).

3 Evaluation of emission control options and strategies proposed for city A

Di(2-ethylhexyl)phthalate (DEHP) and diuron were found to be present in the effluent of the WWTP in city A (Seriki & Pettersson, 2009) and a combination of emission control options was proposed in order to reduce the emissions of these pollutants (Seriki et al. 2009). Mitigation options for DEHP for individual sources control emissions included chemical substitution, stormwater treatment, tertiary treatment at the municipal WWTP and voluntary initiatives. Diuron was quantified in the influent and effluent stream of the WWTP, as the compound is no longer sold or legally used, a combination of voluntary initiatives will only be proposed for this compound.

3.1 Evaluating emission control options and strategies for DEHP and diuron for individual sources

3.1.1 Evaluation of individual emission control options

This section evaluates all the different emission control options based on the activities identified as being responsible for the emission of DEHP (di(2-ethylhexyl)phthalate) and diuron. As diuron is not supposed to be used any longer, no sources are listed for this substance (Seriki et al., 2009). Identified sources for emitting DEHP in city A were as follows (Seriki et al., 2009):

- Under coating paste on vehicles: DEHP is used to allow flexibility of the paste and enables good permeability to water in cars, and is released during car use,
- Outdoor cables used for electricity distribution: DEHP is used to allow cable flexibility and good electrical insulation, and is released through cable use and weathering,
- Floor and wall covering: DEHP is used for flexibility and hygiene, and release mainly occurs through use, washing and weathering of the products,
- Building installation: DEHP is present in the cladding and roof membranes to allow good thermal insulation, to provide weathering protection, and for high Ultra Violet light and ozone resistance. The release occurs through weathering,
- Coated textiles: DEHP is contained in textiles used for products including chairs, tents, swimming pool covers canopies, and curtains for lorries. DEHP is emitted through weathering and washing,
- Clothes and footwear: DEHP is no longer used in clothes or shoes in the EU, but imported clothes from non-EU countries could still contain DEHP in shoe soles for example where they are used to provide better flexibility. The release is done through the use and washing of the products,
- Sealants and adhesives: DEHP is used in windows and doors framing for weather resistance. It is released through the weathering or washing of products,
- Lacquers and paint: DEHP is released through the use and the ageing of products,
- Building installation coated metal sheets: Sheets are covered with DEHP, and releases occur through manipulation of the material and weathering,
- Production of heat: the combustion of PVC products releases (as contaminants) DEHP to the air or to land via contaminated ash,
- Solid waste collection: DEHP leaches from PVC objects commonly contained in solid waste.

The evaluation provided scores for the options available for DEHP and diuron taking the local conditions of city A into consideration (see tables 3, 4 and 5 for the scores, detailed description is found in Seriki et al., 2009). In bold are presented the options identified as best to adopt. Emission control options focused on activities for which emission of PPs could be quantified and that had been identified as potential sources in the city. As data was not available from industry regarding the processes that cause industrial PP emissions no options could be proposed for these activities. In the Swedish city of Malmö, it has been shown that industries have substituted DEHP and households are therefore the principal contributor to DEHP in municipal wastewater (Flygare, 2008). The exclusion of evaluating control options for industrial sources may therefore not contribute significantly to the overall picture.

Some emissions were omitted from the evaluation because there was insufficient data to support the evaluation process. For example, the amount of DEHP emitted hospital by activities (blood bags, catheters…) could not be quantified because hospitals did not want to communicate information on consumption and disposal of DEHP containing materials. These unaccounted emissions could contribute a significant discharge of priority pollutants on a municipal scale however. Chemical substitution of DEHP consists of finding alternative chemicals for products or processes that do not release DEHP. It was noted that further studies are needed to asses the efficiency and durability of replacing DEHP in the long-term (e.g. 20 years) for some products or processes. Even if chemical substitutions for some applications are known to be efficient, it is still important to evaluate them as their application to all sources may not be possible by 2015 but may still have consequences on release of PPs in the city.

The tertiary treatment step in municipal WWTPs was chosen to consist of an advanced oxidation process (AOP) using ozone, as it was the most practical and efficient to apply within the existing WWTP configuration in City A.

Voluntary initiatives for reducing DEHP releases from domestic products relate to the use of wallpaper for example, instead of paint containing DEHP. Other voluntary initiatives for DEHP included the replacement of PVC flooring by wood or tiles. Household voluntary initiatives were evaluated, however several factors such as time, convenience and money restriction at the consumer level can vary from one household to another and an uncertainty due to such variations could not be accounted for in the conducted evaluations. Details of voluntary initiatives are proposed in table 4 for floor and wall covering. In addition, small initiatives are also listed in the table for households for diffuse sources within the house.

Table 3: Evaluation of emission control options for DEHP in city A (1 being the lowest ('worst') score and 3 being the highest ('best') score)

DEHP												
Type of use **Type of source**	**Possible measure**	**Criteria**										
		Technical feasibility	**Technical efficiency**	**Probability to reach WFD target**	**Operational costs**	**Investment costs**	**Impact on the supply chain**	**Impact on employment**	**Impact on drinking water**	**Delay of implementation**	**Total score**
Under coating paste release on vehicles	Chemical substitution (replace by Di-isonyl phthalate (DINP))	3	2	2	2	2	2	2	1	2	18
	WWTP tertiary treatment by AOP	**3**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**3**	**22**
	Stormwater treatment (infiltration basin)	3	2	2	1	1	3	3	1	3	19
	Voluntary initiatives (apply local wastewater treatment for car wash facilities; buy cars with eco friendly labels)	2	1	2	2	2	2	2	1	2	16
Distribution of electricity (outdoor cables)	Chemical substitution (replace by DINP)	2	2	2	2	2	2	2	3	2	19
	WWTP tertiary treatment by AOP	**3**	**3**	**2**	**2**	**2**	**3**	**2**	**1**	**3**	**21**
	Stormwater treatment (infiltration basin)	3	2	2	1	1	3	3	1	3	19
	Voluntary initiatives (use of moisture cured, PE for jacketing or FEP for building wire; use of PE XLPE, EPDM or PVC/nylon for power cable)	1	1	2	1	2	2	2	1	1	13

DEHP											
Type of use **Type of source**	**Possible measure**	**Criteria**									
		Technical feasibility	**Technical efficiency**	**Probability to reach WFD target**	**Operational costs**	**Investment costs**	**Impact on the supply chain**	**Impact on employment**	**Impact on drinking water**	**Delay of implementation**	**Total score**
Release during use of floor and wall covering	Chemical substitution (replace by DINP or Di(2-ethylhexyl)terephthalate (DEHT))	2	2	2	3	2	2	2	1	1	17
	WWTP tertiary treatment by AOP	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**1**	**3**	**23**
	Stormwater treatment (infiltration basin)	3	2	2	1	1	3	3	1	3	19
	Voluntary initiatives *	3	2	2	2	1	1	2	1	2	16
Release during building installation	Chemical substitution (replace by DINP or Alkylsulphonic phenyl ester (ASE))	2	2	2	2	1	2	2	1	1	15
	WWTP tertiary treatment by AOP	**3**	**2**	**2**	**2**	**2**	**3**	**3**	**1**	**3**	**21**
	Stormwater treatment (infiltration basin)	3	2	2	1	1	3	3	1	3	19
	Voluntary initiatives (store DEHP material indoors, encourage the use of alternative building materials)	3	2	2	2	2	2	3	1	1	18
Release from clothes and footwear	Chemical substitution (replace by DINP or DEHT or DINCH, ASE)	3	2	2	2	2	2	2	1	2	18
	WWTP tertiary treatment by AOP	**3**	**3**	**3**	**2**	**2**	**3**	**1**	**1**	**3**	**21**

DEHP											
Type of use **Type of source**	**Possible measure**	**Criteria**									
		Technical feasibility	**Technical efficiency**	**Probability to reach WFD target**	**Operational costs**	**Investment costs**	**Impact on the supply chain**	**Impact on employment**	**Impact on drinking water**	**Delay of implementation**	**Total score**
Release from clothes and footwear	Stormwater treatment (infiltration basin)	3	3	1	2	1	3	1	1	3	18
	Voluntary initiatives (prefer clothes and footwear that can be traced and for which guaranty for not using DEHP is possible)	3	2	2	3	2	2	2	1	1	18
Release during the use of sealants and adhesives	Chemical substitution (replace Di(isononyl)cyclohexane 1,2-dicarboxylate (TOTM))	3	2	2	2	2	2	2	1	1	17
	WWTP tertiary treatment by AOP	**3**	**3**	**2**	**2**	**2**	**3**	**3**	**1**	**3**	**22**
	Stormwater treatment (infiltration basin)	3	3	2	2	1	3	3	1	3	21
	Voluntary initiatives (avoid sealants with DEHP)	3	2	2	2	2	2	2	1	1	17
Release during the use of lacquers and paint	Chemical substitution	3	3	3	2	2	2	2	1	1	19

DEHP											
Type of use **Type of source**	**Possible measure**	**Criteria**									
		Technical feasibility	**Technical efficiency**	**Probability to reach WFD target**	**Operational costs**	**Investment costs**	**Impact on the supply chain**	**Impact on employment**	**Impact on drinking water**	**Delay of implementation**	**Total score**
Release during the use of lacquers and paint	**WWTP tertiary treatment by AOP**	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**1**	**3**	**23**
	Stormwater treatment (infiltration basin)	3	2	2	2	1	3	3	1	3	20
	Voluntary initiatives (use of wall paper without DEHP or water base paint)	3	2	2	3	2	2	2	1	2	19
Release from coated textile	Chemical substitution (replace by DINP or DEHT or DINCH, ASE)	3	2	3	2	2	2	2	1	1	18
	WWTP tertiary treatment by AOP	**3**	**3**	**3**	**3**	**2**	**3**	**3**	**1**	**3**	**24**
	Stormwater treatment	3	3	1	2	1	3	3	1	3	20
	Voluntary initiatives (use of textiles not treated with DEHP or avoid exposing textiles outside)	3	2	2	2	2	2	2	1	1	17
Release during use of building installation coated metal sheets	Chemical substitution (replace by DINP, DEHT, DINCH or ASE)	2	2	2	2	2	2	2	1	1	16
	WWTP tertiary treatment by AOP	3	3	2	2	2	3	2	1	3	21
	Stormwater treatment (infiltration basin)	**3**	**3**	**3**	**2**	**1**	**3**	**3**	**1**	**3**	**22**
	Voluntary initiatives	3	2	2	2	2	2	2	1	1	17

DEHP											
Type of use **Type of source**	**Possible measure**	**Criteria**									
		Technical feasibility	**Technical efficiency**	**Probability to reach WFD target**	**Operational costs**	**Investment costs**	**Impact on the supply chain**	**Impact on employment**	**Impact on drinking water**	**Delay of implementation**	**Total score**
Production of heat	Chemical substitution	Chemical substitution is not possible as the sources are too diverse									
	WWTP tertiary treatment by AOP	3	3	1	2	2	3	2	1	3	20
	Stormwater treatment (infiltration basin)	3	3	1	1	1	3	3	1	3	19
	Voluntary initiatives (collect DEHP material and send them for appropriate treatment/disposal with DEHP solid wastes)	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**1**	**3**	**23**
Waste collection	Chemical substitution	Chemical substitution is not possible as the sources are too diverse									
	WWTP tertiary treatment by AOP	3	1	1	2	2	3	3	1	3	19
	Stormwater treatment (infiltration basin)	3	1	1	2	2	3	3	1	3	19
	Voluntary initiatives (pick out objects containing DEHP and treatment/disposal apart)	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**1**	**3**	**23**

* Examples of voluntary initiatives coul be for PVC wall covering: Use woven textiles, wood fiber/polyester blend, cellulose polyester blends, wood pulp/recycled paper blend, biofiber products or polyolefin/synthetic textiles. Examples of voluntary initiatives for PVC floor covering could be use cork and linoleum material, wooden floors, tyles. Examples of voluntary initiatives for the use of material containing DEHP in household could be workshop for citizen to understand of eco-labelling and implications of choosing or not eco-labelled products, best practices to avoid DEHP release within the house when one cannot afford alternative products (e.g. vacuum washing of window frames, carpets, walls…)

Table 4: Evaluation of emission control options for diuron in city A

Diuron											
Type of use **Type of source**	**Possible measure**	**Criteria**									
		Technical feasibility	**Technical efficiency**	**Probability to reach WFD target**	**Operational costs**	**Investment costs**	**Impact on the supply chain**	**Impact on employment**	**Impact on drinking water**	**Delay of implementation**	**Total score**
Release during application of pesticides	Chemical substitution	1	1	1	2	2	3	2	1	2	15
	WWTP tertiary treatment	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**1**	**3**	**23**
	Stormwater treatment	3	3	2	2	2	3	3	1	2	21
	Voluntary initiatives	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**1**	**3**	**23**

Evaluations of all emission control options have shown that the addition of a tertiary treatment to the municipal WWTP would be the most efficient in most cases. A key factor in this finding is that no one can foresee the direct results of applying a chemical substitution and thus robustly assess if such an emission control option would be successful on a long or short term. Chemical substitution on a large scale is not known to have been undertaken for any specific products to date and no examples have been made publicly available for DEHP. The willingness of industries and municipalities to apply the proposed emission control options cannot easily be measured; especially when dealing with local industries that depend on larger industrial groups. For example, applying DEHP substitution within a local industry may not be possible as modifications could have an impact on industries worldwide responsible for delivering primary goods. Prohibiting the use of DEHP would have to be done at a national level to assure a deadline for DEHP uses and substitutions at a local level. Municipalities, despite their determination to assure an ideal environment to their citizens may have competing (and higher) priorities that may need to be dealt with before looking into chemical substitution.

Criteria chosen for the evaluation of emission control options were judged to be the most important in enabling a realistic judgement on the efficiency of each emission control strategy in relation to priority pollutant reduction. The full performance of ECS can only be judged accurately when knowledge can be gathered on all industrial processes operating in the city, on the chemical properties of priority pollutants and on the efficiency of the substitution in different objects. Several industrial activities were identified in city A, but emitting processes were not known so no emission control options could be suggested for these sources. The scoring adopted in the previous section could not be utilised due to a lack of data and the evaluation for aspects such as delay of implementation and impact on supply chain were subjective. In other words, the conditions were set in a way that it was assumed that all the proposed emission control options were actually implemented and with no major difficulties. This however, may be a false representation as a deeper analysis of social behaviour and acceptance at the consumer and industrial level would be necessary to robustly establish the actual implementation success and this was not possible within the scope of this task.

The impact on the supply chain is also difficult to assess because substitution products could be more expensive to the consumer as a result of the research and development that has gone into them, thus creating less demand and finally a decrease of end users. When dealing with chemical substitutions, there are clearly a lot of unknown factors, therefore the chemical substitution was often given a score of 2. Those factors could have been better or worse depending on the substitution and the emission control option. Moreover, assessing the efficiency of chemical substitution in objects specific to the city is complex as no results were found concerning DEHP chemical substitution on a large scale. Further research is necessary in order to evaluate the efficiency of chemical substitution, the price and the possibilities and this is highlighted as a priority research area.

Emission control options involving municipal wastewater treatment options are known to show some success as several researches on the subject are documented and cost and efficiency data were also found in the literature (DHV, 2002). End of pipe treatments, such as advanced oxidation processes (AOPs), are considered as tertiary wastewater treatment for which extensive research has been conducted on a laboratory scale but not many full-scale systems are yet implemented worldwide. However, the fate and consequence of DEHP degradation products of in and on the environment, when using different AOPs is not well documented. Therefore, such tertiary treatment of wastewater should be used as a temporary solution, but further thoroughly studied. The aim of using end of pipe treatment technology is to apply an immediate and effective solution while at the same time implementing a long term and more sustainable solution. As it can be seen from table 3, activities that were identified as being the main contributors of DEHP to the urban environment and that could be emitted from different sites across the city such as releases from under coating paste on vehicles, clothes and footwear (different households through the washing machine or wear out in streets) or lacquers and paint (through application within households/businesses) had higher scores when a tertiary treatment was proposed at the WWTP. Numerous sources are responsible for emitting DEHP into the environment so it could take many years before seeing any substantial changes when applying chemical substitution or voluntary initiatives. End of pipe technology however (in this case ozonation), would allow an immediate change by decreasing DEHP concentration in the WWTP effluent. Stormwater treatment was judged more appropriate when dealing with the release during the use of building installation coated metal sheets. Indeed, releases from such activities to the urban surface are expected to be more important than releases into the municipal wastewater treatment plant in the city. As the stormwater and wastewater network in the city are separate, more focus should be given to stormwater treatment in order to avoid diluting DEHP concentrations by discharging stormwater into wastewater. Rule et al., (2006) noted higher concentrations of DEHP in wastewater (5-57µg/l) than concentrations in stormwater (0.5 to 1.5µg/l) in his case. Adding stormwater to wastewater would decrease the concentration of DEHP in wastewater and thus require treating a more important volume of wastewater at the WWTP

Possible errors that may not be accounted for in the evaluations would be the investments and operation and maintenance costs for which only rough approximations could be made. The technology has shown good removals at laboratory scale for DEHP and the ozonation is a process that is applied in some WWTP due to its antibacterial properties. City-specific investments and costs for this end of pipe treatment depend on the content of organic matter in the effluent stream of the WWTP and also on the average water discharge. Those factors could influence the final investment and maintenance costs. End of pipe treatments should ideally be the last solution to apply to reduce priority pollutants in wastewater due to the possible formation of degradation products. Alternatives would be to apply this treatment during periods when DEHP peaks are expected (e.g. dry weather followed by heavy rain's first flush effect). This would limit expenses linked to the tertiary treatment application use by applying it during specific times of the year.

Voluntary initiatives usually aim at proposing an alternative to the use of products containing priority pollutants. As a result, reduction of the release of PPs is theoretically expected, however, when dealing with voluntary initiatives, the success of emission control options heavily depends on the ‘buy in’ by consumers. Time is often needed to understand and then accept changes. Depending on the level of commitment, the awareness of consumers, the outcomes of emission control option could take years before showing positive improvements. The voluntary initiatives concerning the production of heat and solid waste collection showed the lowest scores. Those activities emit DEHP via the burning or the collection of DEHP containing products. DEHP released by both activities are not emitted directly into wastewater or stormwater. Particles of DEHP are possibly released via incineration but the percentage that may come from this combustion may not account for all that is found in the ashes. Therefore reducing this emission using an end of pipe treatment for these activities would not be efficient, which explains the low scores for both these options. Chemical substitution was not considered here because a list of products burned or collected containing DEHP needs to be compiled in order to propose chemical substitution for each. As not all of these products are known and that knowledge on possible chemical substitution for each of these products would need to be assessed and conducted separately, it was decided not to propose chemical substitution as data was not sufficient to conduct such an evaluation. The voluntary initiatives were expected to be best as those imply the use of alternative products to those containing DEHP and it was judged that this would be more realistic on a household level.

Tertiary wastewater treatment and voluntary initiatives scored equally for the release of DEHP from building installations or materials. Similar scores are due to the fact that DEHP released from the materials may mainly be discharged into wastewater (e.g. PVC pipes) and stormwater (e.g. PVC windows, doors, under coating) making their removal easier using end of pipe technology. Voluntary initiatives would consist of using DEHP free material when constructing new buildings or renovating; and such voluntary initiatives have scored higher in general for city A. These choices would contribute to an immediate reduction of DEHP release, but factors such as the number of objects to replace yearly and their emission to the urban environment greatly influence the rate at which DEHP concentration would decrease. The awareness and commitment within the population is central to the success of these initiatives, and they are expected to require a longer time frame compared to end of pipe technologies. Stormwater treatment facilities scored lower than tertiary wastewater treatment because the investment cost and maintenance costs are expected to be higher in the short term as facilities need to be constructed.

Diuron is a substance that is no longer marketed or used so it was estimated that adopting voluntary initiatives consisting of campaigns to inform the population about the importance of returning pesticides and on making workshops to educate in alternative ways to maintain a healthy garden not using pesticides, would be more efficient than chemical and technological treatment options.

A criterion presented in the matrix that did not influence the emission control option evaluation was the impact on drinking water within the city. Drinking water is taken from another surface body than the WWTP discharge outlet. This surface water is not used as a source for potable water and is directly discharged into the sea. Assessing the presence of PPs in such media is difficult because interferences from NaCl present in seawater would create an increase of limits of quantification (due to the sample dilution) with no guarantee of achieving exploitable results (Seriki & Pettersson 2009). For both reasons it was decided not to evaluate the impact on this water body in the city.

3.1.2 Evaluation of combinations of emission control options (ECECO)

Several DEHP sources were identified in the city (tasks 2.4 and 2.5) and emission control options were proposed for the 11 most important sources. For each of nine sources four emission control options were proposed and evaluated at an individual level. When evaluating each emission control option, the impact of the reduction of this specific source in each city (taking into account other sources) was considered. Result obtained in the previous section for each emission control option for each source was used to assess three overall ECSs for the city for the 11 major DEHP sources. These strategies entail:

1. Voluntary initiatives,
2. Advanced WWTP process,
3. Stormwater treatment.

The evaluation of the combination of emission control options has shown that for the identified main sources of DEHP, advanced WWTP processes at the municipal WWTP would be the most efficient (table 5). The stormwater treatment would be second with voluntary initiatives last. The advanced wastewater treatment process (AOP) was estimated to be the best option as most of DEHP is discharged into the wastewater. DEHP released by outdoor activities (cables, under coating, building) are discharged into the sewer network with the first flush (stormwater runoff). The first flush is the portion of stormwater with the highest concentration of pollutants especially if no rain has occurred over several days. It is therefore expected that the concentration of DEHP present in the first flush will be important. In order to guarantee better surface water quality, first flush flows are immediately sent for treatment in the municipal wastewater treatment plant of city A.

Table 5: Evaluation of emission control options for multiple sources in city A

Type of use/source	**Emission control options scores**			
	Chemical substitution	**Voluntary initiatives**	**Advanced WWTP processes**	**Stormwater treatment**
Under coating paste release on vehicles	18	16	22	19
Distribution of electricity (outdoor cables)	19	13	21	19
Floor and wall coverings	17	16	23	19
Building installations	15	18	21	19
Clothes and footwear	18	18	21	18
Sealants and adhesives	17	17	22	21
Lacquers and paints	19	19	23	20
Coated textiles	18	19	24	20
Building installation coated metal sheets	16	17	21	22
Production of heat	-	23	20	19
Waste collection	-	23	19	19
Total	**157**	**197**	**237**	**215**

DEHP released by indoor sources is directly discharged into wastewater. Voluntary initiatives are the least favourable as the success of the reduction options strongly depend on the willingness and number of consumers ready to adopt such a measure.

3.2 Pricing and evaluating ozonation and filtration processes in city A

The proposed tertiary treatment option for the municipal WWTPs of the city is ozonation as it appears to be the most practical given the existing process configuration. Costs for removing up to 80 % of DEHP using ozonation was estimated to be between 0.05 and 0.10 € per m^3 for a WWTP of a capacity of 200 and 1000 m^3 (DHV, 2002). Knowing that the WWTP treats approximately 7,884,000 m^3 on a yearly basis an estimation of 394,200 € to 788,400 € would be necessary for the ozonation process. An additional 20,000 € would be needed for the salary of one person employed to assure the operation of the process (none of the existing employees at the WWTP are trained to do so) and additional maintenance fees are also to be expected. Water costs in the city is of 4.26 € per m^3 (drinking water + wastewater treatment); on adding the price of the ozonation the final price would be between 4.31 € and 4.37 € per m^3 (to the consumer).

No treatment technologies were proposed for diuron because the compound is no longer legally applied and concentrations in wastewater are likely to decrease with time. The ozonation process, however, was also found to contribute to the reduction of diuron. In addition to the ozonation treatment costs, analysis of influent and effluent PP concentrations would be necessary to follow the removal of DEHP in the WWTP. DEHP should be monitored weekly in both flows, and monthly in wastewater sludge. This would require analysis in duplicate at least twice per week. DEHP analyses on water are known to cost 78 € and 90 € for sludge, so a final sum of at least 34,608 € (35,000 €) should be expected for the analysis of the WWTP (Seriki & Pettersson, 2009).

Table 6: Evaluation of end of pipe treatment in case city A for DEHP

Type of treatment technology	Criteria				
	Technical feasibility	Technical efficiency	Financial consideration	Environmental impact	Total score
Ozonation	3	2	1-3	3	9-11
Infiltration basin	3	3	3	3	12

3.3 Evaluating emission control strategies for DEHP and diuron in City A

The ECSs proposed in this section are evaluated with the assumption that the proposed initiatives are adopted and applied within a time frame of 10 years. The assumption is that no changes in the industrial and economical activities will occur within this same time frame and that no alternative emission reduction of PPs will be proposed in the city during this period of time. Tables 8 to 11 present the scoring obtained for each criterion. Adjustments were done for the cost criteria based on data obtained from the budget allocated for environmental issues in the city (wastewater treatment, urban cleaning, awareness programs…). It was calculated that an average of 23.4M€ per year had been spent these four past years for environmental purposes (including investment and maintenance). Scoring details were therefore modified as follow:

Financial consideration: if the necessary O&M costs to take into consideration are in the range: 16-23M€ a score of 1 is given, 8-16M€ a score of 2 is given and <8M€ a score of 3 is given.

Table 7: Multi-Criteria Assessment of the ECSs for DEHP and diuron with respect to the Criterion "technical feasibility"

Compound	Emission Control Strategy	Explanation	Score
DEHP	Voluntary initiatives	Several incentives proven to be successful in time have been done at the national level to promote eco friendly material (subsidies when buying less CO_2 emitting cars, solid waste recycling program, subsidies when using environmental friendly material for construction). Applying different type of voluntary initiatives with the help and support from the local, regional and national administrations would be feasible.	3
	Advanced WWTP process	The use of ozonation as a tertiary treatment is feasible as this technology is nowadays used as tertiary treatment. Moreover, space wise the construction of such a process within the existing WWTP facility would be feasible. As it was mentioned in previous tasks of WP2, the city has for the past years reserved a significant budget in assuring better water quality by improving the sewer network and assuring stormwater storage facilities in order to treat it.	3
	Stormwater treatment	The city's objectives are to improve stormwater retention and treatment. Proposing infiltration basins across the city at strategic places (in industrial areas, parking lots) would enable to respond to both objectives while assuring additional green areas. A score of 2 was assigned because this technique would require modification in the actual land planning within the city whereas the other 2 ECSs would not.	2
Diuron	Voluntary initiatives	As mentioned for DEHP several incentives have been successfully been put in place therefore it is expected to have the highest score. The combination of several voluntary is therefore necessary to assure a fast reduction of diuron. Moreover, as the population is the main contributor of DEHP in the city, success for such an ECS is expected.	3

Table 8: Multi-Criteria Assessment of the ECSs for DEHP and diuron with respect to the Criterion "technical efficiency".

Compound	Emission Control Strategy	Explanation	Score
DEHP	Voluntary initiatives	Environmental awareness is something that is progressing within the city. A period of 10 years enables to organise and plan voluntary initiatives in an efficient and durable way. In addition, the time frame gives an important lapse of time in the application of the different initiatives. Depending on the adopted voluntary initiatives some to major reduction are to be expected. As the time frame may be to short, a score of 2 was given.	2
	Advanced WWTP process	The ozonation treatment process has proven to remove up to 80% of DEHP from wastewater (Lindeboom, 2006). As first flush stormwater and wastewater are treated in the WWTP, it is expected that a major reduction of DEHP occurring from the urban area will occur.	3
	Stormwater treatment	The infiltration basin is the stormwater treatment that is believed to be the most appropriate for the city. Moreover, the infiltration basin was the highest ranked best management practice for DEHP. Reduction is expected, however the most important sources are not directly discharged in stormwater therefore significant amounts are still expected to be found in wastewater occurring from the urban area.	2
Diuron	Voluntary initiatives	As diuron is no longer legally applied, only existing stocks detained by consumers may be used. Ways to encourage people of returning stocks, disposing of their existing stocks and using alternative ways for weed control would be efficient.	3

Table 9: Multi-Criteria Assessment of the ECSs for DEHP and diuron with respect to the Criterion "cost efficiency".

Compound	Emission Control Strategy	Explanation	Score
DEHP	Voluntary initiatives	Costs associated with voluntary initiatives were not found for the specific city. Several initiatives were proposed and each of them will vary in price. Based on information obtained on the average annual budget for environmental purposes, costs are expected to be below 8 M€ as this represents 34% of the total budget for environmental issues which is too high for the city.	3

	Advanced WWTP process	The average price calculated for the operation and maintenance of having an ozonation process at the municipal WWTP would be between 400000€ and 800 000€ depending on the characteristics of the WWTP.	3
	Stormwater treatment	Cost for the making of an infiltration basin were estimated to be between 8800€ and 25800€ for a 0.25acre basin and from 30 000€ and 78600€ for an acre basin. The average annual operational and maintenance cost of such a basin would be of 750€ for a 0.25acre basin and 1900 € for an acre basin (SWRPC, 1991). So far the city needs to plan storage for 209000m^3 stormwater. The exact surface area to be used for such facilities was not communicated but it was understood that the municipality made the appropriate land planning for such facilities.	3
Diuron	Voluntary initiatives	Costs associated with voluntary initiatives were not found for the specific city. Several initiatives were proposed and each of them will vary in price. Based on information obtained on the average annual budget for environmental purpose it is expected to be below 8 M€ as this represents 34% of the total budget for environmental issues which is too high for the city.	3

Table 10: Multi-Criteria Assessment of the ECSs for DEHP and diuron with respect to the Criterion "environmental impact".

Compound	Emission Control Strategy	Explanation	Score
DEHP	Voluntary initiatives	In the case all voluntary initiatives are applied (tables 3 and 4), DEHP reduction is foreseen. The extent to which reduction will succeed will depend on which voluntary initiatives are the most popular. However, by concentrating on initiatives such as sorting out waste containing DEHP or advocating for alternative building materials (for indoor and outdoor purposes). Medium reductions are expected.	2
	Advanced WWTP process	The first flush of stormwater is treated (water containing the highest load of pollutants) in the WWTP as well as domestic and industrial wastewater. The process has proven to decrease up to 80% of DEHP and as the main DEHP route into surface water is through the WWTP discharges. Major reductions are therefore foreseen.	3
	Stormwater treatment	Stormwater treatment will reduce PPs discharges from the city by treating discharges from outdoor sources. As	1

		only a few sources emit to stormwater (building installation, outdoor cables….) and DEHP mainly is discharged to wastewater, not treated by this option, only minor reduction is expected.	
Diuron	Voluntary initiatives	Encouraging initiatives to avoid using or to dispose of diuron containing pesticides would help in reducing the diuron emission in the city. As the compound is no longer authorized, it is expected that its emissions will reduce in the 2 years to come. However, applying voluntary initiatives will probably enhance the reduction in illegal releases faster and therefore this strategy is given a medium score.	2

Table 11: Overall evaluation scores using the multi-criteria assessment for DEHP ECSs

	Technical feasibility	Technical efficiency	Cost efficiency	Environmental impact	Total score
Stormwater	3	2	3	2	10
Advances WWTP process	3	3	3	3	12
Voluntary initiatives	2	2	3	1	8

4 Comparing results from different evaluation matrices

4.1 Combination of emission control options versus multi-criteria assessment in city A

The final scores obtained using both ECS evaluation matrices are displayed in table 12. Both ECS evaluations place the advanced WWTP process as the most efficient ECS for city A. The similarity in results is due to the fact that wastewater and the portion of stormwater that is the most polluted are treated in the WWTP. Therefore, applying a tertiary treatment to reduce DEHP emissions from the city's WWTPs will have a major impact on the overall reduction of DEHP emissions from the city. Stormwater treatment scored second using the evaluation of combination of emission control options (ECECO) and last using the multi-criteria assessment (MCA); while voluntary initiatives scored inversely. Differences in ECS ranking between both matrices are due to the higher number of criteria in the evaluation of individual emission control options; and to the fact that all individual sources were evaluated as well as their combinations.

Technical feasibility and technical efficiency were criteria used in both matrices. Cost efficiency was used as criteria in the MCA while in the ECECO costs were split in operational and investment costs. This splitting of costs in the ECECO enabled to have a more sensible analysis of financing the ECS. The difference could not be clearly made between both factors in the MCA which lead to an approximation. The ECECO enabled to have further details on the financial and predicted consequences of using emission control options using all of them on several sources within the city, while the MCA looked in to the global outcome valuating most emitting activities over less emitting.

The criterion of reaching the WFD was not exactly assessed in the MCA. The corresponding criterion in this matrix aimed at assessing the overall impact after the application of an ECS and thus ranking the ECS between themselves. In the ECECO, the idea was to assess whether or not specific emission control options and then ECSs could enable to reach the WFD targets. As assessment had been done for each emission control option, the final results in the ECECO were more accurate than the overall ECS evaluation in the MCA.

The socio economic situation of the city after the application of the ECS was considered in the ECECO matrix and it was considered as background information (with assumption that no changes would occur). The fact of having the impact on the supply chain, impact on employment and delay of implementation criteria facilitated the prediction of gains or losses to be expected by applying the ECS. The ECECO matrix enabled to have additional information on which impact the application of the ECS could have in the city which for some stakeholders (industries and municipalities) could be of interest.

Table 12: Scores of ECS using two ECS evaluations for DEHP reduction in city A

Emission Control Strategies	**Scores**	
	Clustered ECO based on 9 criteria	**ECSs based on 4 criteria**
Voluntary initiatives	197 (3rd in the order of preference)	***10 (2nd*** in the ***order of preference)***
Advanced WWTP process	**237 (1st in the order of preference)**	**12 (1st** in the **order of preference)**
Stormwater treatment	***215 (2nd*** in the ***order of preference)***	8 (3rd in the order of preference)

Differences between voluntary initiatives and stormwater treatment in the MCA are due to the criteria of technical feasibility and environmental impact. Voluntary initiatives were given a higher score based on the fact that previous environmental campaigns had been conducted within the city and given positive results. Stormwater treatment, despite the fact that the city is foreseeing to store stormwater to treat it after important rain events was allocated a lower score. A lower score was assigned because stormwater treatment facilities would require rethinking the city’s urban planning. This was seen as an important inconvenience compared with the voluntary initiatives. For the environmental impact criteria, voluntary initiatives were given a higher score. It was assumed that if voluntary initiatives were applied to all sources, these induce greater PPs reduction than stormwater treatment.

Results obtained for both ECSs could have differed by giving stormwater treatment a higher score than voluntary initiative as scores were quite close in the MCA approach. The uncertainty linked to the expert judgement should be considered for both approaches. The perception used when evaluating ECSs may have granted higher uncertainties using the MCA as this matrix evaluates a global impact, while the ECECO first evaluates the local impact of an emission control option for a given source followed by a global impact for all emission control options. Uncertainties linked to the lack of data are also important; information from industrial activities did not allow proposing any ECS for industrial activities. Even if all important sources mentioned in the city are dealt with, the extend to which unaccounted sources participate in DEHP discharge within the city is not known. Ways to decrease such uncertainties would be to have actual campaigns to assess the discharge of DEHP of each activity but this would imply too many measuring campaigns and therefore important financial needs.

When using both evaluation matrices, a strong knowledge of the socio-economical situation as well as the city's involvement regarding environmental issues is important. Experiences and results on previous environmental campaigns are important to know as this enables to know more about the municipality's state of mind regarding environmental issue. However, yesterday's successes do not guarantee that today's propositions will become tomorrow's successes. A missing fact while performing city A ECSs' evaluations was the lack of a recent study on the actual social context and state of mind of the municipality. Information gathered during the last 4 years was collected (budget of the city, priorities over the years) to assess the municipality's main interests. Unfortunately, no recent studies on the population's state of mind and willingness to participate to such environmental programs were made available. The general assumptions were that an ECS was applied and accepted by all stakeholders; yet these assumptions may not be accurate.

Both evaluation methods have their own advantages and drawbacks. On one hand the ECECO enables to take into account all identified emitting sources, evaluate several aspects (technical, environment and socio economical) and compare different control options for the same source but knowledge on the city's (political background, economical interest, urban planning and budget) is needed to assess possible ECS outcomes, scoring remains unsure for some reduction options (when no data is available) and strong knowledge social aspects of the city is of importance. On the other hand MCA enables to have a global approach for ECS outcomes, scoring is allocated in a simpler way and only the main contributing sources are addressed, but knowledge on the city's expenses is necessary to readjust the criterion's scoring, environmental impacts are mainly based on the reduction of PPs discharge (and not on the compliance with WFD standards) and more assumptions have to be done (which are not always accurate).

5 Evaluation of emission control strategies proposed for city B

In city B several priority pollutants were found above detection limits either in the municipal wastewater effluent or the sludge. Of these, DEHP, cadmium, mercury, benzo[a]pyrene and pentaBDE were chosen because these substances were found in effluents or sludge and because information about the polluting sources were available (Jamtrot et al., 2010). Of these substances cadmium, benzo[a]pyrene and pentaBDE were also found in local receiving water bodies but none of them were in high enough concentrations to compromise the surface water environmental quality standards.

As knowledge about the variety and importance of the different sources is crucial to give suitable control options and later to evaluate different control options or strategies, the sources are first described, followed by evaluation of a range of ECSs. Jamtrot et al. (2010) showed the importance of different sources why these are listed below, according to their decreasing importance. Numbers given are from that report, and describes, for each source:

- Releases, which is the sum of releases of a specific PP to water, air and soil.
- Emissions to surface water, which is emissions to surface water, direct or after transport through the sewage system and treatment of water at a WWTP.
- The given numbers are used in calculations of efficiency of the highest scored ECS.
- For the scoring of cost criteria for city B:
- score 1 means a cost of more than 1 million €,
- score 2 means 5000-1 million €, while
- score 3 means less than 5000 €.

This is a deviation of numbers used in the method description, and was chosen as more realistic for the city in consideration, and as the numbers used in the method chapter would result in score 3 for all evaluated ECSs. The purpose of scoring is to see relative differences between the evaluated strategies.

5.1 Evaluating emission control strategies for DEHP using multi criteria analysis

5.1.1 Sources for DEHP in city B

- **Waste in the environment**[2] contributes with 60-70% percent of the known releases (with a calculated release of 38tonnes/year, with emissions to surface water of 2.66tonnes/year). During use and disposal of products and articles, particles and fragments are abraded from them, and in Jamtrot et al. (2010) the dispersion of these particles was separated from release from the use of products from which the particles originate. As the DEHP emitted from this source is in the particulate form, some of it is likely to still be in this particulate form when it ends up in sewage sludge.
- **Floor and wall coverings** were regarded sources with no emissions to surface water in Jamtrot et al. (2010) as these results in indoor releases. The emissions are as molecular release (by diffusion within and from floor and wall carpets in buildings to the indoor air or to a cleaning solvent) or included in particles (released from floor and wall covering in buildings during wear and tear), with according to Jamtrot et al. (2010) an overall release of 4tonnes/year. Using data of efficiency of the city’s WWTP gives that 1.25% of the amount of DEHP in incoming water is emitted through effluent, indicating that 0.05 tonnes/year could be emitted to surface water from this source. This source was assumed to be the most important source in relation to influent to WWTP, and thus to sludge.
- **Use of coated textiles** in households is the second largest known source in relation to surface water (0.14tonnes/year), while the total release was calculated to be small (0.5tonnes/year) compared to the sources listed above. The reason why this source was seen as more important in relation to surface waters is that this release will partly be transported by stormwater.
- **Use of lacquers and paint** (release 0.8tonnes/year, and emissions to surface water 0.11tonnes/year).
- **Use of sealants and adhesives** (release 0.5tonnes/year, and emissions to surface water 0.06tonnes/year).
- DEHP-containing abrasion particles from different PVC materials contribute significantly to the load, but their DEHP content may, to a large extent, not be detected in chemical analysis of receiving surface water.

5.1.2 Evaluating emission control strategies for DEHP for multiple sources

Table 13: Criterion Technical feasibility using the multi-criteria assessment for ECS

Compound	Emission	Explanation	Score

[2] **Waste in the environment**’ is a term used in the risk assessment report for DEHP (Luxembourg: Office for Official Publications of the European Communities, 2003). The explanation of this term is abrasion particles released from different materials containing DEHP, for example polyvinylchloride (PVC) plastics with DEHP added as a phthalate to make the material flexible. These abrasion particles are widely spread in the environment.

	Control Strategy		
DEHP	Voluntary initiatives	The voluntary initiatives proposed are to promote replacing DEHP-containing flooring, wall coverings, coated textiles etc with materials without DEHP, and city initiated campaigns directed towards public and private house owners. The main source was identified as “waste in the environment” which will only indirectly be affected by these measures. Several incentives proven to be successful in time have been done at the national and local levels to promote eco friendly material, for example for choosing construction products with lower environmental impact (BASTA, 2010). However, these have typically dealt with changing the use of chemicals in new products, and there is limited experience in applying such strategies to the types of sources that dominate the DEHP releases (related to long-lived products).	2
	Advanced WWTP process	Ozonation is at present regularly used as tertiary treatment and is therefore a feasible technology. Moreover, space wise the constructing of such a process within the existing WWTP facility would be feasible.	3
Compound	**Emission Control Strategy**	**Explanation**	**Score**
DEHP	Stormwater treatment	The infiltration basin is the stormwater treatment that is chosen for the evaluation in this city. It was the highest ranked BMP for DEHP. Proposing infiltration basins across the city at strategic places (in industrial areas, parking lots) will reduce the emissions of PPs with stormwater (including some of the emissions from the dominating source ‘Waste in the environment’) while assuring additional green areas and increasing ground water production. A score of 2 was assigned because this technique would require modification in the actual land planning within the city whereas the other two ECSs do not.	2

Table 14: Criterion technical efficiency using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
DEHP	Voluntary initiatives	Environmental awareness is something that is progressing within the city. A period of 10 years enables to organise and plan voluntary initiatives in an efficient	2

		and durable way. In addition, the time frame gives an important lapse of time in the application of the different initiatives. The life lengths of the materials releasing DEHP is typically approximately 20 years, and the use of DEHP was phased out around 2000, indicating that within the time frame of 10 years a lot of the releases will have been eliminated even without any special efforts. A campaign dedicated at speeding up this process could increase the efficiency to some extent.	
	Advanced WWTP process	The ozonation treatment process has proven to remove up to 80% of DEHP from wastewater (Lindeboom, 2006).	3
	Stormwater treatment	A significant reduction is expected. Stormwater is an important route of DEHP emissions to the environment.	3

Table 15: Criterion cost using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
DEHP	Voluntary initiatives	There is a lack of information concerning costs associated with voluntary initiatives in general. Estimations of the costs associated with previous public awareness campaigns have been presented, and indicated that the costs are relatively limited. However, the cost of an early replacement of DEHP-containing products such as floorings and wall coverings could be significant for the house-owners.	2
	Advanced WWTP process	The average price calculated for the operation and maintenance of having an ozonation process at the municipal WWTP of this city would be 15M€ according to calculations from Björlenius (2009). With a 50 year depreciation period (which according to Björlenius (2009) is a reasonable time frame) the annual cost will be 0.3M€ (not taking into account the uncertainty related to inflation, interest etc).	1
	Stormwater treatment	The cost for constructing BMPs was calculated based on the calculations for semi hypothetical case city archetype EI (Scholes et al., 2010). In EI the cost for constructing BMPs on 0.05% of the city's area would be between 12500 and 2332500€/year. City B's land area is roughly 40% of EI's. It is then assumed that constructing the same kinds of BMPs on 0.05% of the land area in City B would cost between 5000 and 933000€/year. The differences in salary costs are then not included.	2

Table 16: Criterion environmental impact using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
DEHP	Voluntary initiatives	The suggested initiatives are mainly directed towards applications that are emitting DEHP to the wastewater system, whereas most of the load to surface water comes from stormwater. The initiatives will therefore have a limited impact.	2
	Advanced WWTP process	As most of the load to surface water comes from stormwater, improving the wastewater treatment will have a very limited impact.	2
	Stormwater treatment	Stormwater treatment will enable to reduce PPs discharge into the city by treating discharge from outdoor sources. As the dominating source is emitted into stormwater (waste in the environment) an important reduction is expected.	3

Table 17: Summary table for DEHP

DEHP	Technical feasibility	Technical efficiency	Cost efficiency	Environmental impact	Total score
Voluntary initiatives	2	2	2	2	8
Advanced WWTP process	3	3	1	2	9
Stormwater treatment	2	3	2	3	10

Whilst no big differences between the alternative ECSs were found, the stormwater strategy seems to be the most important in reducing emissions overall. Eco-labelling and information campaigns are voluntary ways of reaching households using products that contain DEHP. Voluntary initiatives by industry have already resulted in some substitutions of DEHP such as the substitution of DEHP-containing floor and wall covering products. Green procurement by important stakeholders, such as large real estate owners, should be encouraged regarding those products that are still in use. An information campaign for regular vacuum cleaning is also to be considered. Instead of washing floors (where the used water goes in the sewer) the particulate matter goes to solid waste and thereby to incineration. Another benefit of this would be related to indoor climate, in relation to human beings. Calculating the efficiency of a full introduction of the stormwater strategy, using the numbers for emissions from the mentioned sources above (2.66+0.05+0.14+0.11+0.06 = 3.01 kg/year as a total emission to surface water) and emissions from stormwater (2.66+0+0.14+0.10+0.06 = 2.87 kg/year, using numbers found in work by Jamtrot et al., 2010), gives a reduction in emissions by 95% or to 0.14tonnes per year. This implies a major importance of this strategy. The reason why this is not seen in the evaluation is partly due to the high score of technical feasibility and efficiency of the strategy advanced WWTP process which can specifically target the removal of DEHP, and partly due to a medium score for technical feasibility of constructing new stormwater BMPs due to the associated requirements for modification of city planning and development.

5.2 Evaluating emission control strategies for cadmium using multi criteria analysis

5.2.1 Sources for cadmium in city B

- **Long range transport** of cadmium was calculated to be the greatest source (11kg/year), contributing to the emission of 4kg/year to surface water.
- **Car washing** releases cadmium through the washing of metal parts, detergents and deposited particles, and is the second largest known source with a total release of 8kg/year and an emission to surface water of 1.3kg/year. The release depends on whether the car wash is performed on the street or at a car washing facility as the discharge to sewer would vary leaving the wastewater potentially subject to a varying level of treatment before entering the sewage system. The importance of this source might be overestimated due to application of new techniques to treat waste water from car washing facilities.
- **Artist paint** where cadmium is a constituent of the pigment was found to be the third largest known source with a release of 4 kg/year, and emissions to surface water of 0.6kg/year.
- **Contaminant in zinc** results in a release of cadmium from constructions that contain zinc with a calculated release of 1 kg/year and emissions to surface water of 0.6kg/year. The uncertainty in numbers is important, from 0.01kg to 10kg, due to a large span in release factors.
- **Food** can contain cadmium, especially cereals and potatoes grown on soils with high cadmium content. The release was calculated to be 3.5kg/year, and emissions to surface water were 0.6kg/year.

Jamtrot et al. (2010) found that detergents with phosphorous released 2 kg/year (0.3kg/year going to surface water), but as phosphorous since 2008 is no longer permitted in household detergents in this country, detergents is not considered as a source.

Traffic is a source of cadmium that is responsible for releases of 10kg/year, but the releases were predicted to the air compartment so no emissions from this source were directed to surface water. However, this prediction could be associated with some degree of uncertainty.

5.2.2 Evaluating emission control strategies for cadmium for multiple sources

Table 18: Criterion Technical feasibility using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
Cd	Voluntary initiatives	The voluntary initiative proposed is to encourage artists to replace Cd containing paint. The main source was identified as “Long range transport” which will not be affected by these measures. The city has several years’ experience of successfully reducing the use of cadmium paint by awareness campaigns including advertising in newspapers, magazines, at art schools and in shops for art materials.	3
	Advanced WWTP process	According to Revitt et al. (2009) Cd is removed by nanofiltration.	3
	Stormwater treatment	The infiltration basin is the stormwater treatment that is chosen for the evaluation in this city. It was the highest ranked BMP for Cd. Proposing infiltration basins across the city at strategic places (in industrial areas, parking lots) reduces the emissions of PPs with stormwater (including the emissions from the dominating source “Long range transport) while assuring additional green areas and increasing ground water production. A score of 2 was assigned because this technique would require modification in the actual land planning within the city whereas the other two ECSs would not.	2

Table 19: Criterion technical efficiency using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
Cd	Voluntary initiatives	The fact that artist paint is not the major source means that the efficiency of a continued awareness campaign is expected to be marginal.	1
	Advanced WWTP process	Revitt et al. (2009) indicates nanofiltration gives a Cd removal of 90%.	3
	Stormwater treatment	A significant reduction is expected. Stormwater is an important route of Cd emissions to the environment.	3

Table 20: Criterion cost using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
Cd	Voluntary initiatives	There is a lack of information concerning costs associated with voluntary initiatives in general. Estimations of the costs associated with previous public awareness campaigns have been presented, and it is indicated that the costs are relatively limited. The costs for artists to change to Cd-free alternatives is expected to be negligible (it may even be that the alternative is actually cheaper).	3
	Advanced WWTP process	Investment cost for nanofiltration: 0.04 to 0.64€/m^3 times 135Mm^3/yr gives 5.4 to 86M€ per year over 15 years of life Operation & Maintenance cost for nanofiltration: 0.01 to 3.71€/m^3 times 135Mm^3/yr gives 1.35 to 500M€ per year. Total cost would be 6.75 to 586M€/yr	1
	Stormwater treatment	The cost for constructing BMPs was calculated based on the calculations for semi-hypothetical case city archetype EI. In EI the cost for constructing BMPs on 0.05% of the city's area would be between 12500 and 2332500 €/yr. City B's land area is roughly 40% of EI's. It is assumed that constructing the same kinds of BMPs on 0.05 % of the land area in City B would cost between 5000 and 933000€/year. The differences in salary costs are then not included.	2

Table 21: Criterion environmental impact using the multi-criteria analysis for ECS

Compound	Emission Control Strategy	Explanation	Score
Cd	Voluntary initiatives	The suggested initiative is directed towards an application that emits Cd to the wastewater system, whereas most of the load to surface water comes from stormwater. The campaign will therefore have a limited impact on surface water quality; score1 means no impact which is not the case. Score 2 is therefore chosen.	2
	Advanced WWTP process	As most of the load to surface water comes from stormwater, improving the wastewater treatment will have no impact for the 50% of stormwater that is not treated at the WWTP in this city. The overall impact is	2

		therefore limited. A score 2 is therefore chosen.	
	Stormwater treatment	Stormwater treatment will enable the reduction of the city's discharges of PPs from outdoor sources. As the dominating source is emitted into stormwater a significant reduction is expected.	3

Table 22: Summary table for Cd

Cadmium	Technical feasibility	Technical efficiency	Cost efficiency	Environmental impact	Total score
Voluntary initiatives	3	1	3	2	9
Advanced WWTP process	3	3	1	2	9
Stormwater treatment	2	3	2	3	10

For Cadmium no big differences were found between the strategies. Stormwater BMPs are expected to show potential for the removal of Cd because the majority of releases are atmospheric and also emissions from zinc-containing constructions would have a potential to be treated by this strategy. Appropriate stormwater BMPs would depend on local geography, efficiency of reduction and financial considerations. A simple calculation of the efficiency of the stormwater strategy, using the numbers for emissions from the sources presented in this report (4+1.3+0.6+0.6+0.6 = 7.1 kg/year as a today total emission to surface water, with emissions through stormwater of 4+0.6+0.6=5.2kg/year, if 50% of the emissions from car washing is considered to go to stormwater) and a complete introduction of this strategy in the city, assuming a 100% reduction through this pathway, would give a reduction of emissions by 77%, or a reduced emission of 1.6 kg/year.

Options relating to car washing facilities and users of art paint have similarities. These options[3] could be the substitution of Cd-containing products for those with a reduced or negligible content. Other possibilities are the implementation of legislative measures or voluntary initiatives. Pre-environmental control options relating to these two sources could include the introduction of treatment technologies at car washing facilities, and information campaigns on how to handle art paint waste that contains Cd.

Food as a Cd source is difficult to tackle through pre-application control unless the Cd content of agricultural land is first reduced through changes to current fertilizer practices. Changes to food intake recommendations also have potential. These options would only be included in a very advanced ECS. A more feasible approach is the development of treatment options at WWTPs and through options preventing the release of PPs in the environment.[4]

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[3] All measures put in place before any PP has been manufactured, used, consumed, or released into the environment. This includes substitution, phase-out, voluntary and regulatory initiatives, legislation and preventative measures such as education campaigns. (Eriksson et al., 2009)

[4] End of pipe treatment – Addresses all options that are put in place to remove PPs once they have been manufactured, used or consumed, but before they have been emitted into the environment. This includes municipal and industrial WWTPs, BAT, and greywater treatment. This also includes voluntary and regulatory initiatives, potential ELVs, and recycling-campaigns. (Eriksson et al., 2009)

5.3 Evaluating emission control strategies for mercury using multi criteria analysis

5.3.1 Sources for mercury in city B

- **Dentists, old dental filling** (total release of 6 kg/year, with emissions to surface water of 0.8 kg/year)
- **Human excrements due to amalgam fillings** (total release of 5 kg/year, with emissions to surface water of 0.6 kg/year)
- **Coal combustion installations** (>50MW) (total release of 7 kg/year, with emissions to surface water of 0.3 kg/year)

There are other sources of mercury in city B, such as **non-hazardous waste** (release 9 kg/year) and **crematoriums** (release 1 kg/year), but the emissions to surface water from these sources were calculated to be small or insignificant. Emissions from traffic was found to be the most important (Jamtrot et al., 2010), with erosion of tyres (total release of 77 kg/year, emissions to surface water of 26 kg/year) and erosion of roads (total release of 16 kg/year, emissions to surface water of 5 kg/year) as contributors. These sources were disregarded though, as no validation of these sources was found in literature. Atmospheric deposition was not among sources with data, although this is a known source of mercury, which also increases the uncertainty.

5.3.2 Evaluating emission control strategies for mercury for multiple sources

Table 23: Criterion Technical feasibility using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
Hg	Voluntary initiatives	The main sources were identified as “Human excrements” and “Dentists working with (old) dental fillings”. The latter are dealt with by amalgam traps at dental clinics and neither of the sources are affected by voluntary initiatives by households or municipalities.	1
	Advanced WWTP process	According to Revitt et al. (2009) Hg is removed by nanofiltration.	3
	Stormwater treatment	The infiltration basin would be the stormwater treatment chosen for the evaluation in this city. It was the highest ranked BMP for Hg. A score of 2 was assigned because this technique would require modification in the actual land planning within the city whereas the other two ECSs would not.	2

Table 24: Criterion technical efficiency using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
Hg	Voluntary initiatives	No relevant initiatives were identified.	-
	Advanced WWTP process	Revitt et al. (2009) indicates nanofiltration gives a Hg removal of 90 %.	3
	Stormwater treatment	A significant reduction is expected, but stormwater is not an important route of Hg emissions to the environment.	1

Table 25: Criterion cost using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
Hg	Voluntary initiatives	No relevant initiatives were identified.	-
	Advanced WWTP process	Investment cost for nanofiltration: 0.04 to 0.64 €/m^3 times 135 million m^3/yr = 5.4 to 86 million €/y over 15 years of life. Operation & maintenance cost for nanofiltration: 0.01 to 3.71 €/m^3 times 135 million m^3/yr gives 1.35 to 500 million €/yr. Total cost : 6.75 to 586 million €/year.	1
	Stormwater treatment	The cost for constructing BMPs was calculated based on the calculations for semi-hypothetical case city archetype EI. In EI the cost for constructing BMPs on 0.05 % of the city's area would be between 12 500 and 2 332 500 €/yr. City B's land area is roughly 40 % of EI's. It is assumed that constructing the same kinds of BMPs on 0.05 % of the land area in City B would cost between 5000 and 933 000 €/year. The differences in salary costs are then not included.	2

Table 26: Criterion environmental impact using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
Hg	Voluntary initiatives	No relevant initiatives were identified.	-
	Advanced	Improving the wastewater treatment will have a	3

	WWTP process	significant impact on the load to surface water, as WWTP effluent is the dominating pathway for Hg emissions to surface water.	
	Stormwater treatment	Stormwater is not an important route of Hg emissions to the environment, according to the list of sources, why the environmental impact of this strategy should be low.	1

Table 27: Summary table for Hg

Hg	Technical feasibility	Technical efficiency	Cost efficiency	Environmental impact	Total score
Voluntary initiatives	1	-	-	-	-
Advanced WWTP process	3	3	1	3	10
Stormwater treatment	2	1	2	1	6

No conclusion could be drawn as the data on which individual scorings are developed is considered to be insufficient. Both emissions from erosion of roads and tyres could be treated by stormwater BMPs, or by directing a larger proportion of stormwater to WWTPs. Sources releasing to sewage implies treatment at WWTPs. Options that consider dental amalgam as a source already exist in City B. Amalgam traps are installed at dental surgeries as a semi-voluntary initiative and the local water company has been offering compensation to real estate owners and dentists to encourage them to renew pipes from dental care facilities within their property. The dentists' union has also decided to use amalgam only when there are no other feasible options. As a result, the use of new amalgam has decreased to nearly zero. BAT and other technical options to reduce the release of Hg from coal combustion installations and crematoriums have also decreased the emissions of Hg to air in City B. Ignoring the big uncertainties described (both in relation to sources and pathways), the efficiency of adding the strategy advanced WWTP process (nanofiltration) could be calculated. Emissions from indoor sources are then 1.4kg/year (0.8 + 0.6kg/year), using numbers from Jamtrot et al. (2010). This number in relation to all mentioned emissions (0.8+0.6+0.3) is 1.7kg/year and an efficiency of this treatment method of 90% would give a reduction of about 75% or reduce the emissions to about 0.4kg/year.

5.4 Evaluating emission control strategies for benzo[a]pyrene using multi criteria analysis

5.4.1 Sources for benzo[a]pyrene in city B

Domestic greywater[5] from human activities (release 500kg/year) was found to be the only benzo[a]pyrene (B(a)P) emission source to surface water (0.006kg/year). No information was found on the cause of B(a)P-content – domestic grey water is not really a source, but more of a distribution route. Cooking (especially barbequing), smoked food-stuffs and cigarette ashes are some possible explanations.

Jamtrot et al. (2010) stated that there are some important missing sources for B(a)P in city B, when comparing a calculated load to what was found from monitoring campaigns at WWTPs. Such sources could be related to B(a)P released to air within the city, which was not calculated as being deposited there. Some releases from road traffic (release 4.6tonnes/year) and domestic wood burning (release 8.0tonnes/year) are likely to be deposited and redistributed by stormwater to the WWTPs. This is also the case for some smaller sources like municipal waste incineration, cigarette smoke, coal and oil burning. Leaching of B(a)P from bitumen (e.g. roofing), asphalt, and creosote treated wood are sources that were identified as potentially important but could not be quantified due to lacking release factor multiplier information.

5.4.2 Evaluating emission control strategies for benzo[a]pyrene for multiple sources

Due to limited knowledge about the redistribution of B(a)P between air, soil and stormwater after releases from road traffic and incineration of waste and different fuels, it has not been possible to assess the effects of different strategies. The PAH emissions related to domestic greywater from human activities is difficult to control at the source. Improved treatment at WWTPs would be the only option. Stormwater is likely to be the main pathway for PAHs from sources that will deposit from air, such as vehicles and other sources of combustion. Stormwater treatment by BMPs could therefore be considered. Due to lack of information no numbers could be given to describe the efficiency of this ECS though.

5.5 Evaluating emission control strategies for pentaBDE using multi criteria analysis

5.5.1 Sources for pentaBDE in city B

- **Particulate waste** from polyurethane (PU) foam (release 55kg/year) results in calculated emissions to surface water of 3.9kg/year

Most of the pentaBDE is emitted to air, with only abrasion particles found to contribute to the load in the aquatic environment. The use of PU foam (release 66kg/year) and waste handling (release 54kg/year) was found to be a source of emissions to air. The manufacture of furniture (office, kitchen and other) was found to be possibly relevant, since a few such industries were found in the city but as pentaBDE must not be used in production of PU within the EU since 2004, this source was assumed to be insignificant. The phase-out has reduced the stock and the lifetime releases from PU containing articles. PU foam articles has commonly been used indoors, but due to the phase out the nowadays

[5] Domestic greywater is a term that includes sewage water from bath, shower, kitchen sink, wash basin, dish washer and washing machine.

release could be related to abrasion particles present outdoors, though releasing to wastewater through stormwater (combined systems). It may be that the phase-out of pentaBDE has been effective as less pentaBDE was found when comparing calculated emissions to that found by the WWTP monitoring.

5.5.2 Evaluating emission control strategies for pentaBDE for multiple sources

Table 28: Criterion Technical feasibility using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
penta-BDE	Voluntary initiatives	The voluntary initiatives proposed are to promote replacement of pentaBDE-containing products such as PU foam upholstery in furniture. Several incentives proven to be successful in time have been done at the national and local levels to promote eco friendly material (subsidies when buying less CO_2 emitting cars, solid waste recycling program, public awareness campaigns for choosing products with lower environmental impact). However, these have typically dealt with changing the use of chemicals in new products, and there is limited experience in applying such strategies to the types of sources that dominate the pentaBDE releases (related to products already in use).	2
	Advanced WWTP process	No data have been found on the efficiency of advanced wastewater treatment technologies regarding the removal of pentaBDE. We therefore assume that technologies may be available, but need to be further developed to be appropriate for removing pentaBDE.	2
	Stormwater treatment	The infiltration basin was the stormwater treatment chosen for the evaluation in this city. It was the highest ranked BMP for pentaBDE.	2

Table 29: Criterion technical efficiency using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
pentaBDE	Voluntary initiatives	Environmental awareness is something that is progressing within the city. A period of 10 years enables to organise and plan voluntary initiatives in an efficient and durable way. In addition, the time frame gives an important lapse of time in the application of the different initiatives. The life lengths of some of the materials releasing pentaBDE is typically up to 20 years, and the use of pentaBDE was phased out around 2000-2005, indicating that within the time frame of 10 years a lot of the releases will have been eliminated even without any special efforts. A campaign dedicated at speeding up this process could increase the efficiency to some extent.	2
	Advanced WWTP process	No data have been found on the efficiency of advanced wastewater treatment technologies regarding the removal of pentaBDE.	-
	Stormwater treatment	A significant reduction is expected.	3

Table 30: Criterion cost using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
penta-BDE	Voluntary initiatives	There is a lack of information concerning costs associated with voluntary initiatives in general. Estimations of the costs associated with previous public awareness campaigns have been presented, and indicated that the costs are relatively limited.	3
	Advanced WWTP process	No data have been found on the efficiency of advanced wastewater treatment technologies regarding the removal of pentaBDE, and therefore no specific method has been chosen for evaluation of costs.	-
	Stormwater treatment	The cost for constructing BMPs was calculated based on the calculations for semi hypothetical case city archetype EI. In EI the cost for constructing BMPs on 0.05% of the city’s area would be between 12500 and 2332500€/year. City B’s land area is roughly 40 % of EI’s. It is assumed that constructing the same kinds of BMPs on 0.05% of the land area in City B would cost between 5000 and 933000€/year. The differences in salary costs are then not included.	2

Table 31: Criterion environmental impact using the multi-criteria assessment for ECS

Compound	Emission Control Strategy	Explanation	Score
pentaBDE	Voluntary initiatives	Within the time frame of 10 years a lot of the releases will have been eliminated even without any special efforts. A campaign dedicated at speeding up this process could further affect the environmental impact to some extent.	2
	Advanced WWTP process	As no specific technology could be evaluated it was not possible to predict the environmental impact.	-
	Stormwater treatment	Stormwater treatment will enable to reduce PPs discharge into city by treating discharge from outdoor sources. As the dominating source is emitted into stormwater an important reduction is expected.	3

Table 32: Summary table for pentaBDE

Penta-BDE	Technical feasibility	Technical efficiency	Cost	Environmental impact	Total score
Voluntary initiatives	2	2	3	2	9
Advanced WWTP process	2	-	-	-	-
Stormwater treatment	3	3	2	3	11

Substitution has already eradicated much of the pentaBDE releases in the city so future ECSs should focus on waste management and the substitution of old furniture/upholstery and automobile articles/constituents that contain pentaBDE in polyurethane foam. This could be achieved in a similar way as that described for DEHP. Unfortunately data was insufficient to enable scoring for advanced WWTP technologies. From the MCA stormwater treatment seem to be the best strategy. The emissions to surface waters of 3.9 Kg/year is according to calculations in Jamtrot et al. (2010) through stormwater effluent by 3.8Kg/year, why a calculated reduction in emissions by complete stormwater treatment as a strategy would be 97%.

5.6 Using weighting factors

To show how weighting factors could be elaborated DEHP and Cd are used as example PPs, as these were the PPs for which it was possible to complete filled summary tables for city B. The same options are considered for each ECS as described earlier in chapter 5.

For DEHP ozonation was proposed as advanced WWTP process. This is a technique that has proven to be efficient for several organic pollutants, and is in city B considered a feasible technique. In city B there is a major concern about emerging pollutants, such as pharmaceuticals. As some of these pollutants would be oxidised by this technique (Björlenius, 2009) it is possible that the city would be interested in giving this ECS a higher weight. By multiplying the total score from section 5.1, with the weighting factor 2, an increase in score to 18 would be given to this ECS. This would imply this strategy to be much more interesting than the other ECSs, and also to a change from the stormwater to the WWTP stategy to receive highest total score.

Table 33: Evaluation of DEHP where weighing factors are added

DEHP	Technical feasibility	Technical efficiency	Cost efficiency	Environmental impact	Total score
Voluntary initiatives	2	2	2	2	8
Advanced WWTP process	3	3	1	2	9*2=18
Stormwater treatment	2	3	2	3	10

Cadmium is a heavy metal and the content of Cd in sludge is of major concern in the country in which City B is located as recycling of phosphorous from sludge has been seen as an important part of reaching a sustainable development status. As no advanced WWTP technique will both reduce the content of Cd in effluent and in sludge, this is not considered a good solution for this city. As Cd to some extent is coming to the WWTP through stormwater in the combined stormwater/sewage water system, treating stormwater could be a favoured ECS for this city. As this strategy is also efficient in decreasing pollution of receiving water bodies, and there is also a political will to increase the number of beaches, this strategy could be given a higher weight. The total score could in this example be again multiplied by 2 to give an overall score of 20 for the development of a full stormwater treatment strategy.

Table 34: Evaluation of Cd where weighing factors are added

Cadmium	Technical feasibility	Technical efficiency	Cost efficiency	Environmental impact	Total score
Voluntary initiatives	3	1	3	2	9
Advanced WWTP process	3	3	1	2	9
Stormwater treatment	2	3	2	3	10*2=20

As described above, different weighting factors could be added and combined. If there is a low will to increase the price of tap water, and the tap water price includes the cost of treating waste water (which is the case in city B) the WWTP strategy should have a lower weighting factor for cost. If a weighting factor of 0.5 is added to this criterion, the total score for the advanced WWTP process in Table 31 would be 17 instead of 18, and in Table 32 the total score would be 8.5 instead of 9. And if several summary tables are combined for different PPs, a more complex view would be given. Combining Table 31 and 32 would in this case give a total score for voluntary initiatives 18, for advanced WWTP processes (although in this case these techniques are different which might be a reason not to do so) 25.5 and for the stormwater strategy 30. The stormwater strategy would in that case be considered the most preferred option.

Another way to use these matrices and using weighting factors is to look at the low cost strategies. If the voluntary initiative strategy in the case of Cd is inexpensive the city could decide to add a high weight for this criterion, for example 2, which in this case would result in a total score of 12 for this Cd strategy. As this strategy is also seen as technically feasible it could be an option to start with, while the financial situation is waiting to ameliorate, during a recession. Especially if other criteria that are not included in these matrices, like the impact on employment, is seen as important. This ECS could then be chosen although it has a lower score than other ECSs.

6 Comparing outcomes of ECSs using multi-criteria assessment in City A and B

6.1 Comparing ECSs in both cities

For both cities all ECS strategies were assessed for DEHP reduction using the multi-criteria assessment matrix. In city A, advanced wastewater treatment was the best option, followed by voluntary initiatives then stormwater treatment. For city B, stormwater treatment scored best followed by advanced treatment then by voluntary initiatives.

In city A, there is a separate sewer network that enables the stormwater's retention in retention ponds then its treatment at WWTP during low wastewater discharges in the sewer. As municipal wastewater and stormwater are both treated at the WWTP, it was assumed during the evaluation of the advanced wastewater treatment that applying a tertiary treatment would be more efficient than applying stormwater treatment or voluntary initiatives. Applying stormwater treatment would enable reducing DEHP removal in the city, but DEHP present in wastewater would not be removed. As the amount of DEHP discharged in stormwater (sources from urban surface and from atmospheric deposition) is smaller than DEHP discharged directly into the WWTP. In addition, the making of stormwater treatment would require brand new investments (modification of the separate sewer, land planning modifications), it was assumed that stormwater would be the least favourable ECS to apply in the city. Voluntary initiatives scored second, because it was assumed that applying voluntary options to the city would enable better results as these would focus activities know for emitting important amounts and on activities done by a large number of people. For the city, other campaigns to increase awareness on environmental issues were previously done and well accepted by the population. It was assumed that people would willingly participate to the implementation of voluntary initiatives and that these would be successful for a city of this size.

In city B, part of the sewer is combined and the other is separate. Stormwater is discharged in the combined and in the separate sewer. Stormwater discharged in the sewer is treated at the WWTP while stormwater in the separate sewer is discharged into the city's surface water. According to Jamtrot et al. (2009) it was assessed that in city B approximately 1600 kg/year of DEHP was released in the city in surface water, in air and on urban surface. Releases of DEHP in the city are suspected to be due to mainly abrasion particles deposited on urban infrastructures. These particles are later washed off by stormwater and either end in up at the WWTP for treatment or are released into surface water. Applying stormwater treatment would enable to treat more than half of the DEHP emitted in the city explaining the high score for stormwater application. In the case advanced wastewater treatment was to be applied, a little less than half of the emitted DEHP would be dealt with, thus explaining a high score to stormwater treatment in city B, while it is on second place in the ECSs scoring for city A. Concerning the application of voluntary initiatives in city B, it was assumed that their use would require an important investment and a significant population participation to affect DEHP removal by 2015. As the population of the city is above a million, it was assumed that the application of multiple voluntary initiatives would not be as sufficient as the application of stormwater and wastewater treatment technologies. This solution was then evaluated as being the least favourable for the city.

Important differences were noted when calculating the cost of applying the ozonation process in city A and city B. It was estimated that a total of 0.8M€ would be necessary for city A and a total of 15M€ would be needed for city B. Differences in prices are due to several reasons. First of all, city A has one WWTP while city B has 2. Second, the person equivalent (p.e.) of WWTPs in both cities is different.

In city A, the p.e. is of 122 000 while in city B, the p.e. for one WWTP is of 291 500 and for the other of 698 000. The pricing of any water treatment technology depends on the amount of water to be treated, the more water to treat the higher the price. Third, references used to evaluate the cost of using the ozonation process were different for both cities. In city A, material generated from the Socopse project was used while city B used information from a study specific for the WWTPs in consideration (Björlenius, 2009). Using the Socopse information also for city B would give a final cost of ozonation process to be between 6.8M€ and 13.5M€ for city B. Still lower, the higher range using the Socopse project evaluation is closer to the calculated value using the cost data from the local study at the WWTPs in city B.

6.2 The multi-criteria assessment and uncertainties

When using the multi-criteria assessment it was noticed that the differences in scores obtained for the different emission control strategies were small. The use of few criteria created a loss in sensitivity in the assessment of ECS. Indeed, with fewer criteria, more weight had to be assigned to each criterion. During the evaluation process for each criterion, details can be lost to the benefit of others. Moreover, the scale scoring may not be sufficient to well assess differences between ECSs. As a result, great uncertainties can rely on the evaluation as the evaluator may favour a given point over another. The evaluation of the same ECS from a person to another may create important disparities in scoring results. This highlights the importance of well defining the wanted outcomes and to target the stakeholders of importance for ECSs. If scoring can be made in an objective way, adding different weighting factors to the criteria would fill the need of including different views of the evaluator. This would be more transparent, and thereby a way to reduce uncertainties.

7 Conclusion

The task of reducing PPs from an urban area does not reside in finding possibilities but rather in having the possibilities adopted by the general population. Nowadays, many people prefer to rely on end of pipe technologies as those are seen as an easier way to assure a clean environment. Chemical substitution implies replacing a substance by another in applications or objects; in some cases replacement is possible and can mimic similar properties as the replaced substance. The problem though is that the replacement may be followed by increasing costs that may not be economically-viable for industries or that the substitute substance may cause environmental hazards that we may not yet be aware of. Furthermore, chemical substitution is not technically possible for some substances (Lecloux, 2009). An alternative solution is to concentrate on source control options; in other words changing habits in order to avoid using PPs which would cause major changes at the legislative and industrial scale. For many PPs changes need to be taken at a consumer and industrial level, for improvements to be noticed, however, in most cases this implies increasing the level of investment or in extra expenses for the consumer that may not be willing to pay or change habits. Substantial decrease of PPs release within urban areas can only be made if there are changes at the source. Governments can influence and encourage information campaigns to increase the awareness on situations of PPs discharge in cities but achieving acceptance can take many years. As a result, ECSs such as end of pipe technologies are solutions that should still be considered but should be used on a temporary basis until reduction at the source of PPs is successful enough to avoid such alternatives.

Substitution brought through regulation would be the simplest solution for municipalities, especially for substances that are released in the environment in a diffuse manner as they pose hazards to all biota where the substance is emitted, and not all releases are directed through the WWTP. The problem is that for some applications substitution may not be economically viable or efficient (application wise), or no viable substitution may exist or not sufficient researches on specific substitution application are yet available. A socio-economic aspect to the evaluation is required, which has not been possible within the current report. Voluntary initiatives at a consumer level are useful as a measure to start phasing out a product before regulation for new products is implemented, or to phase out the use of long-lasting products. Voluntary initiatives can also be efficient where the use of the substance does not need to be phased out but where the release should be directed to a more closed system (substances that are destroyed when burned as waste, or where the substance can be re-cycled if the product is removed from the normal waste stream).

When proposing and evaluating different ECSs, it is important to have information about the sources of the chemical substances of concern. This includes information about what sources a specific substance have, the load from each of them and how it is transported (pathways) in the urban catchment, i.e. information from a substance flow analysis. With this information as a basis, performing a MCA could be very fruitful. If MCAs are produced for several substances of concern they can be added together and a combined evaluation of ECSs can be performed. If scoring can be made in an objectively way, adding different weighting factors to the criteria would fill the need of including different views of the evaluator. This would be more transparent and thereby ways to, if not reduce, at least to make uncertainties more visible.

Evaluating ECSs has proven to be a challenging task to conduct. Different approaches have been used to compare ECSs and ECSs for which insufficient information was available (frequently the case), results have a large degree of associated uncertainty. Both evaluation matrices approaches are of use but depending on who is going to evaluate the ECSs, the evaluation matrix to use may differ. Moreover, an excellent knowledge on the urban situation is of importance to conduct fair evaluations otherwise too many assumptions have to be made which can render a false evaluation.

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