Environment Agency

Evidence

Abatement cost curves for chemicals of concern

Report on a pilot study – methodology and indicative examples

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- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Executive summary

This report provides the results of a scoping study to investigate whether abatement cost curves could potentially be used to assist with decision making on chemical risk management under the REACH Regulation (Regulation (EC) No 1907/2006), and potentially chemicals regulation more widely. The project involved the following tasks:

- Reviewing existing literature and methods used to establish abatement cost curves in water and air pollution.
- Based on this review, developing and refining a method for the chemicals sector.
- Proposing specific substances and uses where the method could be applied and tested through case study examples.
- Collecting information to establish the costs of reducing emissions.
- Carrying out the necessary analysis and constructing marginal cost curves for the specific substances and uses considered.
- Making preliminary suggestions for the next steps/further research in developing the method to assess single sector, multiple use abatement cost models and multi-sector, multiple use models.

Draft outputs of the study were discussed at a workshop organised by the European Chemicals Agency in October 2010 and this report takes into account comments received during and following that workshop.

The report includes data collected from the literature and analysis of that data to develop cost curves for three case study substances: short-chain chlorinated paraffins (SCCPs), decabromodiphenyl ether (deca-BDE) and di-2-ethylhexyl phthalate (DEHP).

Taking into account the benefits and potential value of abatement cost curves in chemicals policy decision-making, recommendations have been made for further work.

The data and methodology presented in this report are intended to provide an indication of how cost curves may be used in the future, rather than a recommendation on the final approach to be adopted by any organisation or in any context. Further refinements to data and the method would be required before the results could be used directly in decision-making. Therefore, the findings presented here should only be taken as indicative and are intended to promote debate on whether and how abatement cost curves could be further used in future chemicals regulation.

The information presented on the three case study chemicals is illustrative and does not imply any intention to seek further controls on any substance beyond those that already exist.

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Bill Watts (Environment Agency)

A draft of this report was presented and discussed at a workshop on "abatement costs of chemicals" organised by the European Chemicals Agency on 6 October 2010. We would also like to thank the participants at that workshop for their comments on the report. Some of the suggestions have been taken into account in producing this revised version of the report and the comments have also been useful in identifying priorities for further work.

Contents

1 Introduction

1.1 Background

The Environment Agency has an important role in managing the environmental risks of chemicals under the REACH Regulation, in partnership with the UK REACH Competent Authority. Satisfactory risk management decisions usually depend on the analysis of a complex variety of information on the uses, risks, benefits and costs of the substances of concern.

A challenge for most chemicals, but particularly PBT (persistent, bioaccumulative and toxic) substances, is that impacts are not well understood, making analysis of the benefits of their regulation difficult. The regulatory focus, therefore, is on dealing with these substances on a precautionary basis.

Having an understanding of the cost-effectiveness of measures to control releases of chemicals should help to prioritise actions (a) amongst different substances and (b) for different uses of individual substances.

The main aim of the project was to develop a suitable method for estimating abatement costs to reduce emissions of chemicals and to apply and test the method with selected case study substances.

This project was essentially a scoping study to investigate whether cost curves could potentially be used to assist with decision making in chemicals regulation. For example, such curves could be of use in identifying priorities for action to reduce emissions for chemicals of environmental concern under REACH and under chemicals regulation more widely. The project involved the following main tasks:

- Reviewing the existing literature and methods used to establish abatement cost curves in water and air pollution.
- Based on this review, developing and refining a method for the chemicals sector.
- Proposing specific substances and uses where the method could be applied and tested through case study examples.
- Collecting information to establish the costs of reducing emissions.
- Carrying out the necessary analysis and constructing marginal cost curves for the specific substances and uses considered.
- Making preliminary suggestions for the next steps/further research in developing the method to assess single sector, multiple use abatement cost models and multi-sector, multiple use models.

The intention is that the outputs of this scoping study could link, in the future, to assessment of concentrations in the environment and associated benefits for the environment and human health.

1.2 Purpose of this report

This report summarises the findings of this scoping study and includes the following:

- The outputs of our review of other cost curves approaches.
- A proposed method for cost curves for chemicals of concern.
- Details of the substances investigated as case studies during the project, including justifications for their selection.
- Results of the collection of data on the three selected case study substances.
- Cost curves for each of the three case study substances.
- Suggestions for the next steps/further research in developing the method.

This report is aimed at government decision-makers and other professionals to help them decide whether and how abatement cost curves of this nature are likely to be of value in future chemicals regulation. The report includes suggestions for further work to make this approach more operational in the future.

1.3 Case study substances

The information presented in Sections 5, 6 and 7 of this report provides an overview of the main information readily available for the three case study substances selected for developing cost curves. In particular, it includes information on (a) uses and releases of the substances, (b) current abatement measures and (c) possible future abatement measures. The three case study substances and the basis for their selection are outlined in Section 4 of this report.

The case studies are illustrative examples only, and their inclusion should not be taken to imply any intention of UK Government to seek further controls on any substance beyond those that already exist.

For each of the three substances, available data from the literature was used to construct cost curves, including measures to replace the substance as well as measures to reduce emissions to the environment.

These cost curves were developed primarily to test the methodology. Only data available in the literature was used, much of which is now quite old. No new data was collected. In addition, it was necessary to make a number of assumptions in order to illustrate how the cost curves could be applied in practice (to fill data gaps). Therefore, the costs and emissions abatement potential presented is subject to significant uncertainty and should not directly be used in policy decision-making.

2 Review of existing approaches

2.1 Approach

This stage of the work involved reviewing a range of existing literature on abatement cost curves for pollutants from other regulatory regimes. The aim of this phase was to understand the methods used in developing and applying cost curves and to determine common aspects that could be used to develop cost curves for chemicals of concern.

A standard proforma was developed to allow the methodological approaches to be assessed on a consistent basis. This included consideration of the following aspects associated with the cost curve approaches employed:

- geographical scale (e.g. local, regional, continental, global);
- sectoral coverage (which industry sectors abatement measures have been considered for);
- pollutants covered;
- environmental media (e.g. emissions to air, water, land);
- reference year for the analysis (year in which potential costs and abatement options are assumed to apply);
- how the curve has been developed (including a summary of key steps such as defining the baseline, process for prioritising or selecting sectors/pollutants, identifying measures, cost estimation, producing the cost curves themselves[1]);
- data sources used;
- types of abatement measures (for example substitution versus other types of emissions abatement such as end-of-pipe, activity change, behavioural change[2], fuel switching, technology switching; also whether a multi-sector or multi-pollutant approach was applied);
- any links to the benefits associated with the potential emission reductions;
- details of the outputs of analyses (types of data resulting from the cost curves).

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[1] Assumptions made on specific emissions abatement measures in the various cost curve approaches were not reviewed for this study. These assumptions often vary by sector, pollutant, use, abatement potential and costs and, given that each cost curve may contain tens or hundreds of measures, it was not feasible to review these within the scope of the current work.

[2] In the context of the cost curves reviewed, behavioural change has encompassed changes such as speed reduction in cars/ships to reduce pollutant emissions. In the context of chemicals, this could potentially include implementation of non-technology-based risk management measures, such as precautions used by the general public when handling chemicals.

2.2 What is a cost curve?

Abatement cost curves are essentially a set of measures or options to reduce releases of pollutants to the environment, defined according to the amount of release that each measure could remove, the associated cost of those measures and their cost-effectiveness in terms of cost per unit release removed.

They can be used to help guide investment and policy decisions on whether and how to abate emissions of pollutants, including prioritising amongst different options.

Cost curves can be used to identify the most cost-effective abatement measures that would allow emissions to be reduced to a pre-defined level (such as a national emission ceiling), along with the associated costs of achieving that level. Such a cost curve is illustrated in Figure 2.1. Alternatively, they can be used to show the level of emission that could be abated, along with the cost-effectiveness of doing so, allowing comparison across different emission sources and pollutants. This is illustrated in Figure 2.2.

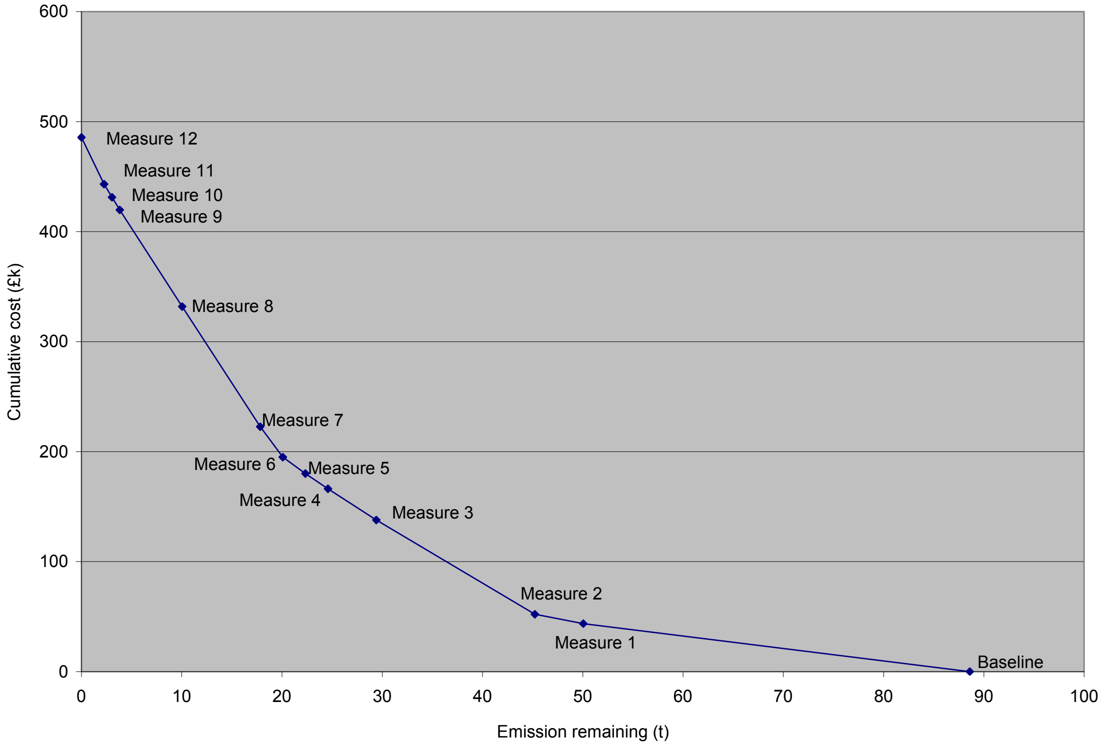

Figure 2.1 Example cost curve showing emission remaining and total cost

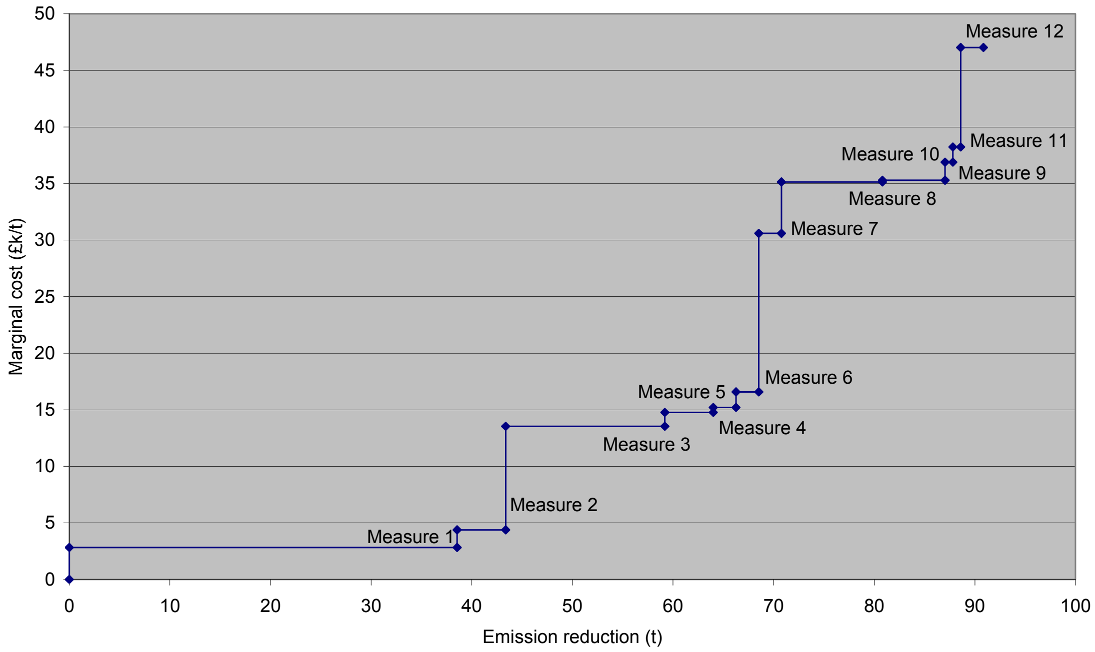

Figure 2.2 Example cost curve showing emission reduction and marginal cost

In this report, the unit costs of a single abatement measure are described as a ‘marginal cost’, being marginal to measures already in place to reduce the emissions (or use) of a particular chemical, for example, on grounds of cost. ‘Marginal’ refers to the unit cost of incremental measures rather than the incremental unit cost of emissions reduction.

The term ‘average cost’ is used to mean the average of the unit costs for a group of measures (though, potentially confusingly, these costs are ‘marginal costs’ in the context of the measures already in place).

More generally, the use of the terms average and marginal depends on the context. Marginal costs are those that result from the last action taken (such as purchase of one extra unit of raw material to increase production by one unit; abatement of one extra unit of emission), while average costs relate to the sum of all costs, including for example fixed costs and overheads, divided by total production (or emission).

Depending on the context, some costs may be fixed in the short term, but not in the long, giving rise to a distinction between Short Run Marginal Costs (SRMC) and Long Run Marginal Costs (LRMC). In the context of this report, the costs of abatement measures are ideally intended to be Long Run Marginal Costs and hence all the costs of an abatement measure, fixed and variable, are included in its marginal cost. However, in the case studies, we were necessarily reliant on information from other literature sources and the cost estimates therein are based on a variety of techniques.

2.3 Literature sources reviewed

The following literature sources were reviewed as part of the analysis:

- Air pollutant cost curves, development of a multi-pollutant measures database and scenario analysis for the Department for Environment, Food and Rural Affairs (Defra).

- International Institute for Applied Systems Analysis (IIASA)'s Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model.

- Assessment of the possible development of an EU-wide NO_x and SO_2 emission trading scheme for Integrated Pollution Prevention and Control (IPPC) installations (including installation-level cost curves and linear programming optimisation model).

- Costs and benefits of abatement options for greenhouse gas emissions from ships arriving at and departing from ports in the UK (cost curves for greenhouse gas emissions from ships).

- Projections of emissions and development of cost curves for non-CO_2 greenhouse gases.

We also reviewed abstracts of studies from a literature search conducted by the Environment Agency as well as other sources of information on cost curves for air pollutants and water pollutants, which adopted broadly similar approaches to those applied above[3].

Much of the review focused on abatement cost curves for emissions to air. Whilst the methodological approaches differ amongst air pollutants (for example, abatement cost curves for volatile organic compounds (VOCs) may often have similar issues to those for typical chemicals whereas combustion products such as NO_x and SO_x are slightly different), the approach for air pollutants could in general be applied to chemicals. There are a number of key differences, however, including:

- The potential for substitution is important for chemicals but not generally for combustion products.

- Releases to different media can occur with chemicals and environmental partitioning will ultimately be important; air pollutants are generally emitted to only one medium.

- There is a huge range of chemicals compared to a relatively small number of well researched 'traditional' air pollutants and greenhouse gases. Inevitably, less information is available for most chemicals and generally no detailed emissions inventories exist.

- A realistic worst case approach is often used to estimate releases of chemicals in risk assessments whereas air pollutant emission inventories are generally intended to provide a best estimate. This reflects the different uses for which the information was originally intended. However, it leads to additional uncertainty in developing cost curves for chemicals.

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[3] For example: Halkos GE (1993) Sulfur abatement policy: Implications of cost differentials, *Energy Policy*, October 1993, 1035. Halkos GE (1994) Optimal abatement of sulfur emissions in Europe, *Environmental and Resource Economics,* 4, 127-150. Halkos GE, Evaluation of the direct cost of sulfur abatement under the main desulfurization technologies, *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 17(4), 391-412. Halkos GE (1998) Evaluating the direct costs of controlling NO_x emissions in Europe, *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 20(3), 223-239.

2.4 Preliminary views following the review of literature

Details of the outputs of the literature reviewed are provided in Appendix A. This includes completed proformas for all of the literature reviewed.

Whilst there are differences in the final data outputs from each of the cost curve analyses reviewed – primarily due to differences in the policy objectives under consideration – there are clear consistencies in the approaches taken.

Business-as-usual (BAU) baseline emission projections provide a starting point for any assessment. They are critical to understand what is expected to happen under the current regulatory regime without any further actions, and to avoid double-counting.

In most cases, sectors and/or pollutants have been prioritised to focus further analysis. For example, the highest emitting sectors have often been selected for investigation of emissions abatement measures, which is particularly relevant for prioritising abatement measures that could be used to meet overall targets/ceilings for emissions.

Analysis generally focuses on measures in terms of technical feasibility (since for some sources of emissions, there may be no technically feasible measures to reduce emissions, meaning these sources would not be a priority for inclusion in cost curves).

In all cases, a series of abatement measures have been developed for the sectors/pollutants of interest based on reviews of relevant literature (such as BREFs, reference documents on best available techniques developed under the Integrated Pollution Prevention and Control directive) and consultation with a wide range of groups (such as technology suppliers, industry associations). Typical information gathered/developed for each measure includes up front capital costs, operating costs, lifetime of equipment and applicability (to different processes and so on).

The measures developed have then been "packaged" together to form different scenarios and/or cost curves. In general, they have been ranked according to cost-effectiveness so that a least cost solution is found. These scenarios/cost curves generally address emissions from multiple sectors and in some cases multiple pollutants at the same time. For example, the GAINS model uses an "optimisation approach" whereby the most cost-effective combination of measures for all pollutants is determined to meet existing environmental targets.

For air pollutants, the environmental and health impacts are relatively well understood (at least compared to emissions to other media) so a number of the approaches reviewed have some links to benefits estimates, either through the use of damage cost functions (monetary value per tonne of pollutant reduced) or via air quality, ecosystem and health modelling (and monetisation – for health impacts only).

The information required to develop cost curves is usually generated through a combination of literature sources and information from industry representatives, such as potentially affected sectors or equipment suppliers. Several of the cost curve approaches combine specific emissions abatement measures (with relevant costs and engineering information on emissions abatement potential) and other measures related to behavioural or activity changes that could reduce emissions.

There are some examples of the use of more sophisticated techniques in developing cost curves, such as optimisation modelling in the context of meeting targets (such as in the GAINS model for meeting European environmental objectives or in the context of NO_x/SO_2 trading under different possible emissions trading scenarios). Given the level of detail in the information likely to be available for most chemicals emissions, it is unlikely that such approaches could be applied for most chemicals without generating significantly more detailed information on emissions and potential abatement as well as associated benefits.

Information requirements and the level of detail in the analysis will depend on how the cost curves are ultimately to be used and what level of certainty is needed. For example, less detail would be required if they were to be used as a pointer for further work, compared to being used as a decision-making tool of themselves. In the latter case, detailed emissions data and information on full substitution/abatement costs might be needed, along with some consideration of the wider impacts that substitution can have (such as on supply chains for alternatives, cost savings and risks of substitutes).

3 Method for the chemicals sector

3.1 Overview

This section provides details of the proposed draft method to apply cost curves to chemicals of concern.

It includes a discussion on some of the key issues faced with chemicals of concern which do not generally arise when developing cost curves for air pollutants or emissions of chemicals to water.

A preliminary method for developing cost curves is set out, including the key stages involved, data requirements and possible data sources. This method involves the development of cost curves at the EU level, taking average emission reductions and costs at the level of sectors or uses of chemicals.

Finally, we have attempted to test the method on a hypothetical example substance, prior to applying the method to 'real' case study substances.

3.2 Key issues for chemicals of concern

3.2.1 Overview

Other cost curves have typically been developed by assessing the implications of abatement measures that affect specific emissions sources and releases to one environmental medium.

Whilst we believe it is feasible to develop a comparable process for estimating abatement cost curves for chemicals of concern, a number of complexities need to be considered. These are discussed briefly below.

3.2.2 Different environmental media

Under REACH and other chemicals regulation, emissions to all environmental media are of interest. However, abatement measures may be specific to one environmental medium. Particularly in the context of linking cost curves to the benefits of reduced environmental releases (in the future), it is important to consider emissions to all environmental media (air, water, land, and so on).

Changes in emissions to one environmental compartment may, in some cases, lead to changes in emissions to other compartments. Factoring such changes into cost curves is feasible but has the potential to become highly complex, at least in anything other than simple use patterns.

3.2.3 Emissions baseline

Compared, for example, with cost curves for greenhouse gases and traditional air pollutants, the level of information on baseline emissions is typically much less well developed for chemicals.

A realistic emissions baseline needs to be established which may be available from chemical safety reports under REACH or from assessments undertaken by authorities or industry. However, such information may not always be available. Furthermore, information from chemicals risk assessments is often based on ‘realistic worst case’ emissions estimates and so may tend to overestimate actual emissions.

Furthermore, existing risk reduction measures need to be clearly understood.

3.2.4 Potential for substitution of chemicals

A key issue under REACH is that chemicals of concern may be replaced in certain uses. This will affect specific uses directly but it will also lead to emission reductions at other lifecycle stages, which may be to different environmental media than those of concern at the use stage. For example, if a substance is no longer used in a particular application, there will also be a reduction in the emissions associated with manufacture of the substance for that particular use, as well as intermediate steps such as formulation (mixing) with other components.

Because of this, there will be costs associated with the changes to levels of manufacture of the substance, as well as other lifecycle stages. There could also be cost savings at other lifecycle stages, such as reduced waste disposal costs where the presence of dangerous chemicals requires wastes to be treated as hazardous waste.

Furthermore, there could be a variety of other costs and potential cost savings, such as changes in energy use associated with emissions abatement techniques or use of alternative substances. It is therefore important to define the boundaries of the analysis in terms of the economic actors affected and types of cost impacts considered.

3.2.5 Approach to cost estimation

As with any predictive (ex-ante) estimate of the costs of compliance with possible legislative requirements (or indeed other non-legislative measures), the validity of the cost estimates depends on the sources used to derive the data and the methods used in estimating costs. Retrospective (ex-post) studies across various fields have shown that there is frequently a tendency for the costs of compliance to be overestimated. It is therefore important that appropriate means of estimating costs are applied[4].

Cost curves frequently only include the costs of technical emission abatement measures. However, this does not need to be the case and there is no reason why the full costs of compliance should not be included (covering administrative and other costs as well as purely technical compliance costs). It is important that the costs for different measures cover the same types of costs in order for comparisons to be useful. In some of the case study costs in Sections 5 to 7 of this report, there are differences in the types of costs covered in the cost curves because the results have been drawn largely

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[4] Useful sources of information are ECHA’s guidance on calculation of compliance costs (echa.europa.eu/doc/reach/appendix1-calculation_%20compliance_costs_case_restrictions.pdf) and the guidance document on socio-economic analysis as part of restriction proposals under REACH (guidance.echa.europa.eu/public-2/getdoc.php?file=sea_restrictions_en).

from literature sources, rather than being based on a systematic estimation of the costs of each measure.

3.2.6 Cost curves for use or for emissions abatement?

For chemicals, it is possible to develop a cost curve based on measures that could be taken to reduce the overall level of use or consumption of a substance. This could be useful, for example, in cases where it has been determined at a policy level that there is a need to phase out use of a particular substance. The measures in the cost curve would then typically cover actions to replace the substance in its different applications and the costs of doing so throughout the supply chain.

The main alternative is to develop a cost curve based on measures that could be taken to reduce emissions of the substance to the environment. In such cases, the measures could include actions to replace the substance but could also include technical or behavioural measures to abate emissions to the environment at industrial facilities or indeed during other lifecycle phases. Such an approach has a number of advantages, particularly for substances where environmental risks/properties are of concern:

- It more accurately reflects the actual level of harm that might be expected from a substance. A measure that reduces a significant proportion of use (such as a major use sector) may have little environmental benefit if that use is well controlled and leads to only minimal emissions to the environment.
- It potentially allows information to be provided on a wider range of risk management options, not only to prohibit or otherwise remove certain uses of a substance, but also to promote or require specified levels of emission control. This can lead to more cost-effective regulation, particularly when choosing amongst a number of chemicals that require control.

However, cost curves based on emissions abatement are inevitably more complex and resource-intensive than those based on use (because the changes in emissions need to be calculated, including interactions between different lifecycle stages). There are also greater uncertainties in estimating emissions compared to estimating usage, meaning that there is likely to be greater uncertainty in cost curves based on reducing emissions than in cost curves based on reducing use.

The cost curve methodology and case study examples in this report are based on measures to reduce emissions of a substance. The cost curves also include measures that would lead to reduced use of a substance, particularly substitution.

3.3 The proposed method

3.3.1 Overview

Based on the review of literature and experience with developing cost curves for other policy areas, an initial method has been set out, as described in Table 3.1. This sets out the main steps in the approach, data requirements, potential data sources and specific issues to be taken into account in applying the method.

Prior to testing the method on real (case study) substances, we applied it to a hypothetical substance in order to carry out an initial test of the data and calculations that would be needed to take into account the issues specific to chemicals.

Table 3.1 Possible stages in a method to generate cost curves for chemicals of concern

Approach	Data requirements	Data sources	Notes
1. Set boundaries of the cost curves			
1.1 Select substance(s) to be assessed	Identify single or multiple substances to be assessed.		
1.2 Determine the geographical scale	Specify geographical scale (to determine emissions, abatement, costs).		Likely to be EU scale for chemicals of significant concern. However, some data may relate only to releases in one Member State. Emissions of some chemicals have potential global impacts.
1.3 Determine the economic boundary of the analysis	Specify which types of actors would be affected and which cost implications will be considered.		
1.4 Determine the reference year(s) for the analysis	Specify year to which emissions abatement is considered and costs are estimated.		For example 2010, 2015, 2020. Different cost curves could be developed for different years (affecting decisions on timescales for controls/substitution, for example)
2. Quantification of current and predicted future emissions			
2.1 Identify relevant lifecycle stages and uses of the substance	Estimate: • quantity manufactured and number of manufacturers; • imports/exports of the substance; • quantity used in different formulation stages and number of companies; • number of user companies/extent of use; • quantities used in each application type; • trends in use; • quantity (including in articles) passing to different disposal routes (landfill, incineration, recycling, and so on).	• Environmental risk assessments (CSA). • Market research data. • Consultation with industry. • Generic assumptions (based on use category documents, for instance).	It may be necessary to screen out certain uses at this point (such as those leading to negligible release to the environment for which it would be inappropriate to identify additional abatement measures).

Approach	Data requirements	Data sources	Notes
2.2 Quantify current environmental releases	Estimate quantity of the chemical, from each lifecycle stage: • released to air; • released direct to water; • released to waste water treatment plants (WWTP); • deposited on land from WWTP and air; • disposed of to landfill; • recycled; • destroyed (such as through incineration).	• Environmental emissions inventories (such as atmospheric emission inventories, E-PRTR). • Environmental risk assessments (CSA). • Emission scenario documents. • Consultation with industry.	Many environmental risk assessments rely on a worst case approach. Where possible, data should be estimated using the most realistic assumptions/estimates. Releases to landfill have – for the purposes of this study – been excluded when identifying reduction measures (they are not considered relevant for the purposes of cost curves).
3. Existing and planned abatement techniques (the business as usual scenario)			
3.1 Identify and characterise existing abatement techniques and those already planned under current policy (business-as-usual scenario)	Identify relevant abatement techniques and: • to which lifecycle stage each (potential) technique applies; • specific emission source/release mechanisms to which technique applies; • level of uptake for specific emission sources (application rate); • level of emissions abatement achieved through application of the technique; • extent to which technique is used already (such as proportion of companies, uses and/or share of quantity at each lifecycle stage); • trends in uptake of techniques and extent to which they could be applied in reference year.	• Environmental risk assessments (CSA). • European Chemicals Agency (ECHA) risk management measures library. • Consultation with industry sectors affected/experts. • Consultation with suppliers of abatement equipment.	

Approach	Data requirements	Data sources	Notes
3.2 Estimate baseline (annual) environmental releases in reference year	Estimate quantity of chemical released for each lifecycle stage as in 2.2 above	As 2.2 above, with assumptions on likely changes from: • Changes in emission factors/limits resulting from future uptake of abatement techniques (above) and changes in legislation. • Changes in future activity rates at a sector level (e.g. future market intelligence)	Emissions in reference year could be the same as current emissions.
4. Identify and characterise possible future abatement measures			
4.1 Identify possible future measures to reduce emissions	Specify: • selected (prioritised) abatement measures for selected (prioritised) uses; • possible measures that are currently available and credible for the uses/sources concerned; • possible measures that are likely to be available by the reference year; • lifecycle stages and specific sources of emissions to which they could apply.	• Experts in the sectors concerned. • IPPC BREF documents and other guidance. • National sector guidance. • Technical literature on abatement techniques (from equipment suppliers, patents and so on). • Emission scenario documents.	Screening stage to identify technically feasible measures. May include: • replacement with alternative substances; • replacement with alternative techniques; • emissions abatement in industry; • prevention of releases from articles; • specification of waste management practices.

Approach	Data requirements	Data sources	Notes
4.2 Characterise possible future measures	• Maximum feasible uptake for each emissions source (such as percentage of sector/total emission covered). • Average emission abatement potential (such as percentage emission reduction efficiency). • Emissions abatement effect for other lifecycle stages. • One-off costs (such as capital equipment, product reformulation). • Ongoing costs. • Economic lifetime of measure (e.g. technical lifetime, expected amortisation period). • Information on exchange rates and historical inflation.	• IPPC BREF documents. • Equipment suppliers. • Price information on chemicals and alternatives. • Market information on uses for chemicals. • ECHA compliance cost guidance.	Will be important to balance disaggregation of uses/emissions sources (to account for variability in emissions and abatement potential) and data availability (data to disaggregate abatement potential in different Member States may not be available). Potential uptake needs to take into account any existing uptake by the reference year and effect on emissions Measures such as substitution with alternatives will generally affect emissions from several lifecycle stages (such as manufacture, formulation, use, disposal). May need to further disaggregate the analysis (such as subsets of uses) to take into account variability in reduction efficiency, for instance. Uncertainty analysis may also be useful if there is significant variability or uncertainty in data inputs.
5. Development of cost curves			
5.1 Develop spreadsheet (or other) model	All data above.		Suggested modular format – see associated example spreadsheet for hypothetical substance

Approach	Data requirements	Data sources	Notes
5.2 Estimate maximum feasible emission reduction for each measure	Potential annual reduction in emissions for each emissions source for each abatement measure. Include estimate of reductions in releases from other lifecycle stages (where applicable).	Based on maximum feasible uptake and abatement efficiency. Earlier lifecycle stages may also be affected if a substance is no longer available on the market.	
5.3 Estimate equivalent annual cost of each measure	For each measure: • capital costs; • ongoing annual costs; • economic lifetime; • discount rate (for example, 3.5 per cent under UK Government guidance, four per cent under European Impact Assessment guidance, or alternative (Note 2)).	As above.	Discounting has been used when calculating equivalent annual capital costs, to provide comparability amongst measures on a similar basis (based on amortisation period). It also allows comparability on an annual basis with emissions abated. All costs should be presented in constant prices (usually in present day prices), taking into account inflation and currency exchange rates.
5.4 Initial ranking based on cost-effectiveness	For each abatement measure, specify order in which measure would be most preferable based on cost-effectiveness, taking into account total emissions abated (all environmental compartments and all relevant lifecycle stages).	Maximum potential emission reduction (5.2) and equivalent annual cost (5.3).	

Approach	Data requirements	Data sources	Notes
5.5 Determine interactions of measures	For each emission source, specify: • which measures are additive (could be applied simultaneously without altering emission abatement or costs) and implications for total emissions abatement/costs for all measures; • which measures are mutually exclusive (could only be applied independently of each other); • which measures could be applied but effectiveness/costs would be affected by other abatement measures for that source.		For additive measures, those that apply to different uses are likely to be additive, as are those that apply to releases to different environmental media; those applied for certain lifecycle stages could affect downstream uses. For those that are mutually exclusive, assume that the most cost-effective measure is applied first. If an alternative measure could also be applied, the cost curve should only reflect the *incremental* emission reduction and cost that would occur. For those that would be affected by other abatement measures, if the most cost-effective measure is applied first, the next most cost-effective may no longer achieve the same degree of emissions abatement (as remaining emissions will be lower).
5.6 Calculate total emissions abated and total cost for each measure in order of expected preferential uptake	Estimate emissions reductions and costs for each measure, taking into account interaction of measures.		This involves re-estimating steps 5.2 to 5.4 but this time taking into account any interactions to avoid overestimating estimates of emissions abated and cost.
5.7 Present results in order of preferential (most cost-effective) uptake	For each abatement measure, specify: • total emissions abated in reference year; • equivalent annual cost; • cost-effectiveness (£/t of emission abated).		Two different methods of presenting the results graphically are provided for the case studies.

Notes: 1) All emission reductions should relate to total releases to the environment or, preferably, to the initial release medium.
2) UK guidance in HM Treasury Green Book http://www.hm-treasury.gov.uk/data_greenbook_index.htm; EU guidance at http://ec.europa.eu/governance/impact/commission_guidelines/commission_guidelines_en.htm

3.3.2 Testing the method on a hypothetical substance

Prior to testing the method on 'real' case study substances, we tested the above approach on a **hypothetical** substance. Refer to the accompanying spreadsheet for more details[5].

In order to estimate the potential for reduction in releases to the environment, the following hypothetical lifecycle stages and environmental releases were considered.

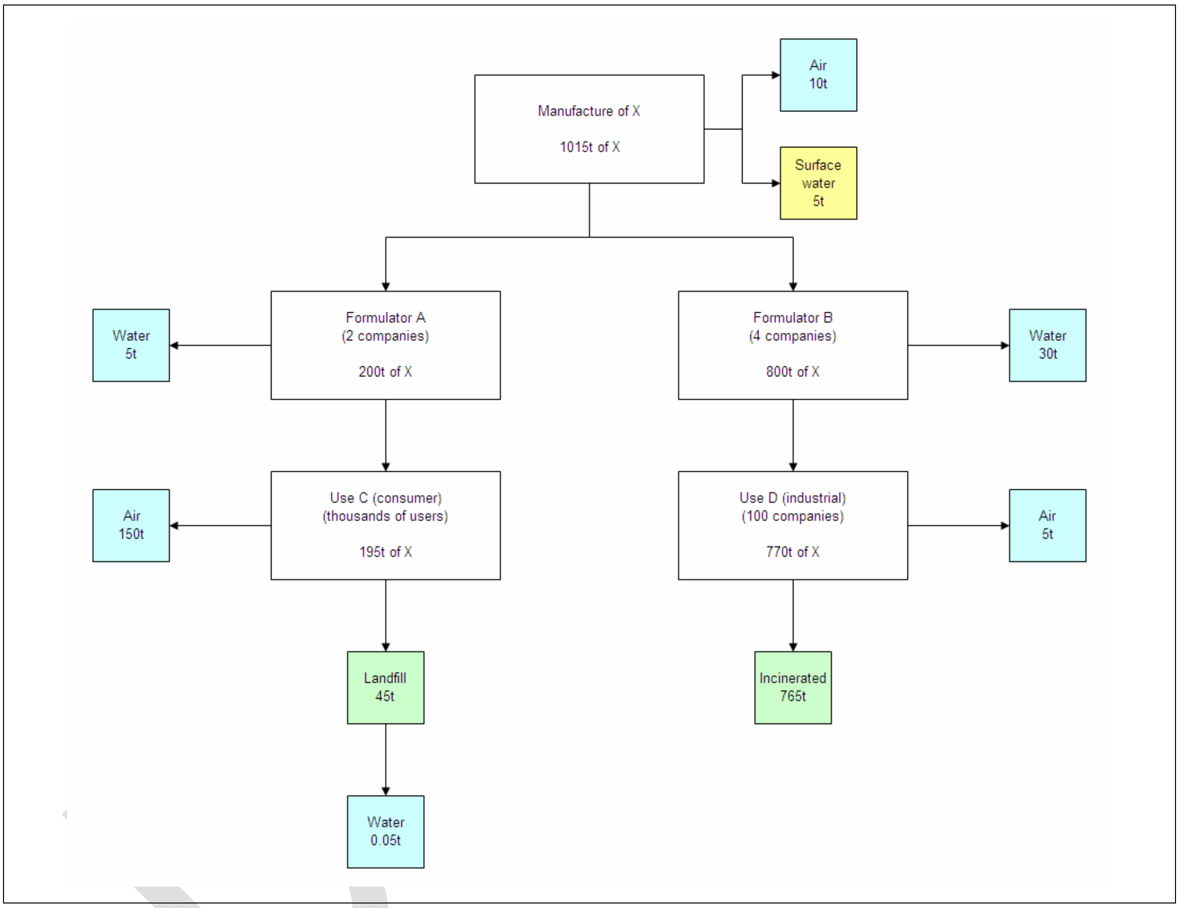

Figure 3.1 Lifecycle flows and releases of hypothetical substance X

The environmental releases from each lifecycle stage are summarised in the accompanying spreadsheet and are shown in the table overleaf. Only emissions direct to the environment (such as to air, direct to surface water, to surface water from WWTP and to land from WWTP) are taken to be 'relevant' releases. Other releases, such as those to incineration, are assumed to be less (or not) relevant because the substance will be destroyed or will otherwise be unable to enter the wider environment.

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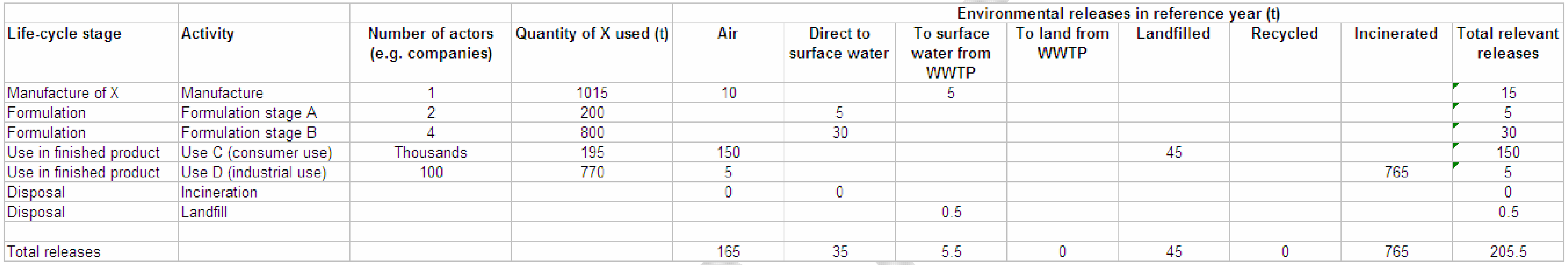
[5] Microsoft Excel® spreadsheets that support the examples are available on request from the Environment Agency's project manager.

Table 3.2 Business-as-usual emissions of hypothetical substance X



				Environmental releases in reference year (t)							
Life-cycle stage	**Activity**	**Number of actors (e.g. companies)**	**Quantity of X used (t)**	**Air**	**Direct to surface water**	**To surface water from WWTP**	**To land from WWTP**	**Landfilled**	**Recycled**	**Incinerated**	**Total relevant releases**
Manufacture of X	Manufacture	1	1015	10		5					15
Formulation	Formulation stage A	2	200		5						5
Formulation	Formulation stage B	4	800		30						30
Use in finished product	Use C (consumer use)	Thousands	195	150				45			150
Use in finished product	Use D (industrial use)	100	770	5						765	5
Disposal	Incineration			0	0						0
Disposal	Landfill					0.5					0.5
Total releases				165	35	5.5	0	45	0	765	205.5

A number of possible future abatement measures were also considered. Again, these are hypothetical and include:

Secondary waste water treatment at manufacturer level. Emission reduction efficiency = 90 per cent. Capital expenditure (capex) = £1 million per company, operational expenditure (opex) = £0.05 million per company, economic life = 15 years.

Primary water abatement for formulator B (additional to existing uptake). Emission reduction efficiency = 80 per cent. Capex = £2 million per company, opex = £0.1 million per company, economic life = 10 years.

Secondary water abatement for formulator B. Emission reduction efficiency = 99 per cent. Capex = £2 million per company, opex = £0.5 million per company, economic life = 10 years.

Substitution in use D. Emission reduction efficiency = 100 per cent for use D. Capex for use D = £3 million per company, opex = £0.01 million per company, life = 20 years (use of alternative).

> Also reduces emissions for formulation stage B with efficiency = 100 per cent (use is removed) and total annual cost = £0.4 million.
>
> Also reduces emissions from manufacture with assumed efficiency = 80 per cent (share of total use) and total annual cost = £0.8 million.

Substitution in use C. Emission reduction efficiency = 100 per cent for use C. Opex for use C = £25 million for all consumers over assessment lifetime of 20 years.

> Also reduces emissions for formulation stage A with efficiency = 100 per cent (use is removed) and total annual cost = £0.1 million.
>
> Also reduces emissions from manufacture with efficiency = 20 per cent (share of total use) and total annual cost = £0.2 million.

Air emissions abatement in use D. Emission reduction efficiency = 95 per cent. Capex = £0.05 million per company, opex = £0.01 million per company, economic life = 12 years.

Note that costs/benefits to suppliers were not considered in this analysis.

These abatement measures were applied to the emissions estimates, numbers of companies and use of the substance at different lifecycle stages. This is illustrated in the accompanying spreadsheet.

It is evident that the interactions of different measures are of particular importance with respect to cost curves for chemicals. Applying a particular measure at one lifecycle stage may affect the potential for abatement and also the costs of subsequent measures that could be applied to other lifecycle stages. This factor needs to be taken into account in finalising the method.

Overall, this analysis shows that, for the types of information that are typically available for chemicals that have been through processes such as EU risk assessments (on releases) and which could reasonably be derived on potential abatement measures, it is feasible to develop abatement cost curves which take into account the additional complexities associated with chemicals.

4 Selection of case study substances

4.1 Criteria for selection of substances

The following criteria were used to select possible substances as case studies in the remainder of the study:

- Non-threshold effects – particularly PBT and vPvB (very persistent very bioaccumulative) substances but also other chemicals with significant potential for environmental release.
- Significance of release to the environment now and likely in the future (based on risk assessments, proposed substances of very high concern (SVHC), published literature or ECHA's analysis of uses and sources and so on).
- Substances that are released to more than one environmental medium.
- Expected level of information on emissions, potential abatement and costs. Whilst it will be important to select some substances with a high level of information, it might also be worth selecting one where the information required is likely to be scarce, in order to (a) determine additional data needs; (b) highlight potential alternative means of estimating the required data.
- Control under other regulatory regimes. For example, pollutants controlled as priority substances under the Water Framework Directive (WFD) may be of particular interest to UK authorities. This would also highlight the potential for interactions in regulatory decision-making, either in the form of potential conflicts or – more likely – for possible synergies between regimes.
- The extent to which the substances are used across a range of sectors and processes. We propose selecting the most polluting sectors/sources for a particular substance rather than all sources in order to make best use of the available resources for the work.

In practice, a key factor in selecting the three case study substances was the extent of information available on uses, emissions and abatement options. Their selection in no way reflects any intention to seek further controls on the substance beyond those that already exist.

4.2 Proposed case study substances

Four substances were initially selected, namely bis(2-ethylhexyl)phthalate (DEHP); bis(pentabromophenyl) ether (deca-BDE); hexabromocyclododecane (HBCDD) and alkanes, C10-13, chloro (SCCPs). In Table 4.1 these are considered against the criteria set out above.

In addition to these criteria, we considered any ongoing work by regulatory authorities and industry on these substances that might or might not support their selection. A deliberate decision was made at the start of our study to limit the data collection for these substances to exclude consultation with industry, given the aim to test the method using data typically available for well-studied substances. Information from industry could be used to supplement and verify some of the data obtained from the literature, but this would best be done once the method was tested for its suitability.

On the basis of this table, three substances were selected as case studies for further analysis: SCCPs, deca-BDE and DEHP.

Table 4.1 Summary of substance selection

Criterion	Substance	Comment
Non-threshold effects	DEHP	Toxic for reproduction (in theory this could have a no-effect threshold).
	Deca-BDE	Not PBT or vPvB though some similarities in its behaviour to a vPvB substance.
	HBCDD	PBT – considered non-threshold.
	SCCPs	PBT and vPvB considered non-threshold.
Significance of release to the environment (at EU level) Released to more than one environmental medium	DEHP	The main releases are to soil (7,600 tonnes per year or t/y) and waste water (3,400 t/y) (600 t/y to air). The use of end-products gives rise to the largest releases to the environment with washing of flooring, releases from underground cables and abrasive releases and pieces lost in the environment as the largest single sources (ECHA, 2009a).
	Deca-BDE	European releases to the environment are estimated as (European Commission, 2002) • 3 t/y (to air as dust/vapour); • 85 t/y (to waste water via WWTP); • 41 t/y (direct to surface water); • 14-15 t/y (to industrial/urban soil); • 939-941 t/y (to landfill/incineration). Several of the release sources are likely to be as dust. Although this release is initially to air, the dust is likely to settle rapidly and be swept up or washed away. Thus this release can be considered as being to solid waste or waste water (European Commission, 2002).
	HBCDD	The release of HBCDD from products during end use is small. Some dust containing HBCDD will be released during the installation of EPS or XPS insulation and ultimately during the refurbishment or demolition of buildings containing these products. Most of the HBCDD released is from coating textiles. The estimated annual release to the environment is 530 kg to air, 1,140 kg to waste water and 560 kg to surface water (ECHA 2009b).
	SCCPs	The major emissions come from the service life of articles and products containing the substance. These are estimated as 0.6-1.7 t/y to air, 7.4-19.6 t/y to waste water, 4.7-9.5 t/y to surface water and 8.7-13.9 t/y to industrial soil. Emissions from industrial processes (formulation and use) are at least an order of magnitude lower than these. SCCPs are also released through their presence in MCCPs; this release is estimated to be below 33.4 t/y (ECHA, 2009c).

Criterion	Substance	Comment
Level of information on emissions, potential abatement and costs	DEHP	Information from emissions databases at UK and EU level, studies for ECHA on releases uses and alternatives and, related to the WFD, data on emissions (at national level), releases and abatement measures including costs.
	Deca-BDE	Information from EU Risk Assessment Report (RAR), less information on abatement costs.
	HBCDD	Studies for ECHA on releases uses and alternatives.
	SCCPs	Studies for ECHA on uses, releases and alternatives. Potential information through WFD on emissions and abatement measures including costs.
Control under other regulatory regimes	DEHP	WFD, IPPC
	Deca-BDE	WEEE, RoHS, WFD, IPPC
	HBCDD	WFD, IPPC
	SCCPs	WFD, IPPC
The extent to which they are used in wide range of different sectors/processes	DEHP	Widely used as a plasticiser in polymer products, mainly polyvinyl chloride (PVC). The content of DEHP in flexible polymer materials varies, but is often around 30 per cent (w/w) (ECHA, 2009a).
	Deca-BDE	Deca-BDE is used as a flame retardant. It is mostly used in applications in the plastics and textile industries. It is an additive flame retardant, being physically combined with the material being treated rather than chemically combined (as in reactive flame retardants). This means that there is the possibility that the flame retardant may diffuse out of the treated material to some extent (European Commission, 2002).
	HBCDD	HBCDD is solely used as an additive flame retardant. HBCDD is used in four principal product types: expanded polystyrene (EPS); extruded polystyrene (XPS); high impact polystyrene (HIPS) and polymer dispersion for textiles. Most is used in EPS and XPS. These products are used widely across the EU in the workplace and in consumer products. The use of XPS and EPS insulation products increased between 2003 and 2007 (ECHA 2009b).
	SCCPs	SCCPs are used as flame retardants and plasticisers. The current use areas of SCCPs have been identified as: rubber (in particular in conveyor belts for use in mines); sealants and adhesives; paints and coatings; and textiles (flame retardant backcoatings). The trend in use of SCCPs is generally downwards, although for most uses where substitution is possible this is thought to have already occurred (ECHA, 2009c).

5 Case study 1 - SCCPs

5.1 Uses and releases

Data on uses and releases of short-chain chlorinated paraffins (SCCPs) in 2004 are provided in the table below, based on a report for ECHA.

Incorporation in rubber and in sealants and adhesives were the major uses in 2007, with use in paints and textiles being minor uses. Total use in 2007 was indicated to be less than 1,000 tonnes in the EU-27; this compares to 13,200 tonnes in 1994. These data were used in developing the cost curve, with an average value taken where a range was given.

Table 5.1 Summary of EU-27 uses and releases of SCCPs in 2004[1]

Use	Quantity used (t)	Release (t)			
		Surface water	**Waste water**	**Air**	**Industrial/ urban soil**
Manufacture		<0.037			
Metalworking	None[2]				
Rubber[3]	<600				
Formulation			<0.1	<0.1	
Processing			<0.5	<0.5	
Paints[4]	<100				
Industrial application			<0.1		
Sealants and adhesives[5]	<300				
Leather	None[2]				
Textiles (backcoating/ waterproofing)	<100		<0.5		
Formulation					
Application			<0.5		
Articles[6]		4.7-9.5	7.4-19.6	0.6-1.8	8.7-13.9
Unintentional formation[7]		<8.9	<13.1	<1.7	<9.7
Total overall	**<1,100**	**<13.6-18.4**	**<20.5-32.7**	**<2.3-3.5**	**<18.4-23.6**
Total used for cost curve[8]		**7.1**	**15.2**	**1.8**	**11.3**

[1] Data from ECHA (2009c). Latest data for which quantified information was available was 2004 (2007 data was qualitative: minor or major use). These are based on 'realistic worst case' estimates of releases for the purposes of risk assessment.

[2] Use restricted in the EU.

[3] Mainly used for rubber conveyors.

[4] Emissions to waste water and air from use (including consumer use) and formulation of paints is reported as negligible.

[5] Emissions to waste water and air from use (including consumer use) and formulation of sealants is reported as negligible.

[6] Uses in articles include rubber goods, building and construction materials (sealants), textiles, and articles painted with paints and coatings.

[7] From impurity in medium-chain chlorinated paraffins.

[8] Total used for cost curve excludes releases from impurity in MCCPs and is based on the mid-range value where a range is specified or the upper value (X) where the value given is e.g. <X.

5.2 Current and planned abatement measures

5.2.1 Specific abatement measures already applied

The main measures already applied for SCCPs are the restrictions on the use of the substance for leather processing and metalworking fluids.

At the end of 2009, SCCPs were included within the scope of the UN-ECE POPs protocol. As a POP (persistent organic pollutant), SCCPs may not be produced or used, although there are exemptions for use in fire retardants in rubber used in conveyor belts in the mining industry and fire retardants in dam sealants[6]. SCCPs are also under review for inclusion under the Stockholm Convention on POPs[7].

Other abatement measures will be applied and the ECHA (2009c) report on uses and releases includes some information on these. However, information on total releases is commercially confidential. Examples of the existing data on measures already applied are given below.

For use as a flame retardant in rubber formulations:

- No specific information is available on controls during raw materials handling or compounding.
- For the conversion step, air emission controls (unspecified) were estimated to be present at 80 per cent of sites, leading to emissions 90 per cent lower than those sites (20 per cent) where such controls were not in place (affecting both emissions to air and to waste water, because emissions initially to air are assumed to settle within the facility and be washed to waste water).

For use in sealants and adhesives, no specific information on emissions controls was presented in ECHA (2009c).

For use in paints and coatings, information is presented (ECHA, 2009c) indicating that emissions from the formulation of solvent borne paints and coatings containing SCCPs are likely to be negligible from well-controlled sites.

For use in textiles:

- Releases from the formulation stage will be removed using a solid extraction system and so will be lower than the generic estimate presented in the report (ECHA, 2009c). However, no quantified information was presented on this.
- No information was presented on abatement techniques applied in emissions from textile backcoating.

No information was presented on specific techniques to reduce SCCP emissions during the service life of articles; however, information was presented on disposal routes that will affect releases.

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[6] Decision 2009/2 Decision listing of short-chain chlorinated paraffins and polychlorinated naphtalenes in annexes I and II to the 1998 Protocol on Persistent Organic Pollutants, ECE/EB.AIR/99/Add.1.

[7] http://chm.pops.int/Convention/POPsReviewCommittee/Chemicals/tabid/781/language/en-US/Default.aspx

5.2.2 Baseline environmental releases in reference year

The year for which there are quantitative data for releases is 2004, as presented in the ECHA report referred to above. As noted in Table 5.1, only qualitative descriptions of releases were given for 2007 and no data were available for more recent years. The restricted uses – specifically use as an extreme pressure additive in metalworking fluids and as a fat liquoring agent in leather processing – were effectively banned in the EU from 2004 under Directive 2002/45/EC. This restriction is now listed in Annex XVII of REACH.

5.3 Possible future abatement measures

5.3.1 Information sources

Abatement techniques involving the use of alternatives were identified with some cost information available from the literature (summarised in Appendix B). Much of the information on substitutes is summarised in the ECHA (2009c) report.

Relatively little information was available on the actual costs of abatement techniques from other literature sources, such as analyses related to control of emissions under the Water Framework Directive (WFD). Restrictions resulting from identified risks to the environment are assumed to enable the meeting of (in particular) standards for the water environment (environmental quality standards, EQS), as described below on surface and waste water. Therefore, it was necessary to make some assumptions on which abatement techniques could be applied and what their implications would be.

A more recent analysis of (amongst other things) the costs of replacing SCCPs in their various applications has been produced for the Dutch authorities (RPA, 2010). This incorporates some of the information from the ECHA (2009c) report as well as providing additional useful information on other costs associated with substitution in certain uses, such as costs of research and development.

5.3.2 Measures included in the cost curve

The following measures were assessed in developing the cost curve for SCCPs:

- Replacement of SCCPs with alternatives in rubber, in particular replacement with MCCPs (measure reference SCCP_R_1), LCCPs[8], (SCCP_R_2) and organophosphates (SCCP_R_3)[9].
- Additional waste water treatment for rubber formulation and processing (SCCP_R_4).
- Thermal oxidation of emissions to air for rubber formulation and processing (SCCP_R_5).

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[8] MCCPs = medium-chain chlorinated paraffins; LCCPs = long-chain chlorinated paraffins.

[9] Substitution with alternatives was separated out into three separate measures, relating to three different substitutes (with different associated costs). These were separated out to illustrate the fact that, due to technical considerations, different substitutes may be used. In practice, it is not known what proportion of current use might be replaced with each substitute, so an approximate assumption was applied.

- Replacement of SCCPs with alternatives in paints and coatings, in particular replacement with MCCPs (measure reference SCCP_P_6), LCCPs, (SCCP_P_7) and phthalates (SCCP_P_8).
- Replacement of SCCPs with MCCP/deca-BDE based coating in textiles (SCCP_T_9).
- Additional waste water treatment for textiles (SCCP_T_10).
- Replacement of SCCPs with alternatives in sealants and adhesives, in particular replacement with MCCPs (measure reference SCCP_S_11), LCCPs, (SCCP_S_12), phthalates (SCCP_S_13) and terphenyls (SCCP_S_14).

Appendix B of this report provides detailed information on the data sources and assumptions used in assessing the emission reduction potential and costs associated with each of these measures.

5.3.3 Cost curve for SCCPs

The table below provides a summary of the key data on each of the measures for inclusion in the cost curve. Further details are included in the spreadsheet[10].

The cost curve is presented graphically in two formats: the first is based on emission remaining and total cost and the second on emission abated and marginal cost. Moreover, the first presents the impacts of each measure as being continuous in that each unit of emission abated is removed at the same cost between data points. In contrast, the second presents each measure as a discrete ‘step’. In practice, the reality is likely to be somewhere in between, in that it would be possible to break down each measure further, such as for individual sub-uses or companies. However, the latter ‘stepped’ approach may be more directly relevant to policy decisions.

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[10] Microsoft Excel® spreadsheets that support the examples are available on request from the Environment Agency’s project manager.

Table 5.2 Summary of cost curve data for SCCPs

Measure	Single-measure cost (£)	Single-measure emission reduction (t)	Cost-effectiveness (£/t)	Incremental cost (£)	Incremental emission reduction (t)	Incremental cost-effectiveness (£/t)	Notes
SCCP_R_1	87,400	15.42	5,670	87,370	15.4	5,670	Alternative to SCCP_R_4 and SCCP_R_5 (measures for abatement of emissions from rubber manufacture)
SCCP_R_2	16,900	1.93	8,780	16,920	1.9	8,780	Alternative to SCCP_R_4 and SCCP_R_5 (measures for abatement of emissions from rubber manufacture)
SCCP_S_11	171,400	6.33	27,090	171,370	6.3	27,090	
SCCP_R_3	56,900	1.93	29,530	56,920	1.9	29,530	Alternative to SCCP_R_4 and SCCP_R_5 (measures for abatement of emissions from rubber manufacture)
SCCP_S_12	27,500	0.90	30,410	27,480	0.9	30,410	
SCCP_S_13	30,000	0.90	33,180	29,980	0.9	33,180	
SCCP_T_10	55,100	0.90	61,180	55,060	0.9	61,180	Alternative to SCCP_T_9
SCCP_T_9	273,800	4.01	68,240	218,750	3.1	70,280	Alternative to SCCP_T_10. Additional emission reduction and cost are incremental to SCCP_T_10
SCCP_P_6	175,700	2.49	70,570	175,730	2.5	70,570	
SCCP_P_7	23,000	0.31	73,790	22,970	0.3	73,790	
SCCP_P_8	23,800	0.31	76,460	23,800	0.3	76,460	
SCCP_S_14	85,000	0.90	94,030	84,980	0.9	94,030	

All data on costs and emission reductions are at EU level. Incremental costs and emission reductions are not necessarily the same as single measure values as they take into account the prior application of more cost-effective measures.

The cost curve does not include the following measures because they do not provide additional abatement beyond other measures (and are less cost-effective): SCCP_R_4 and SCCP_R_5.

Figure 5.1 Graphical cost curve for SCCPs – type 1 (emission remaining and total cost)

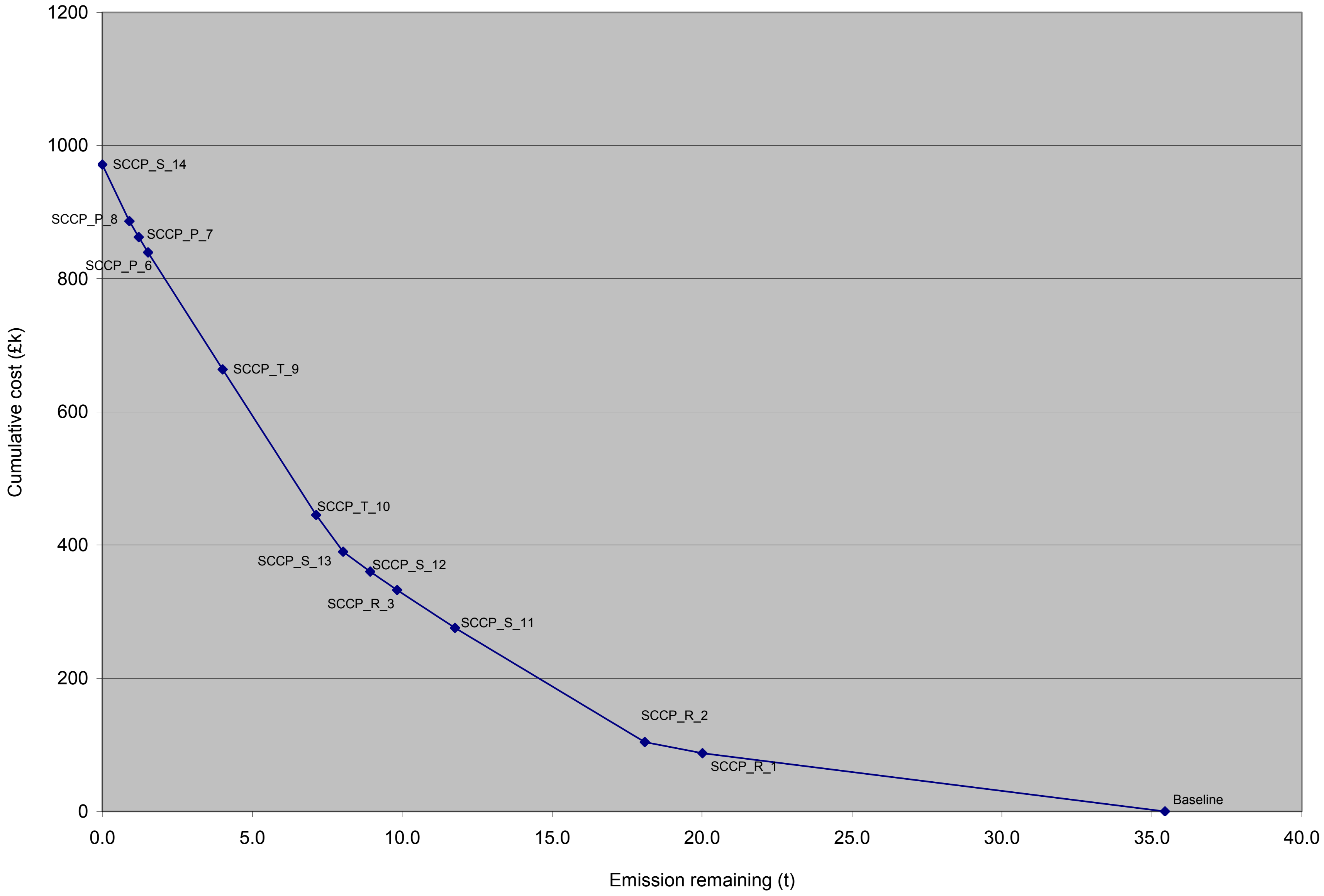
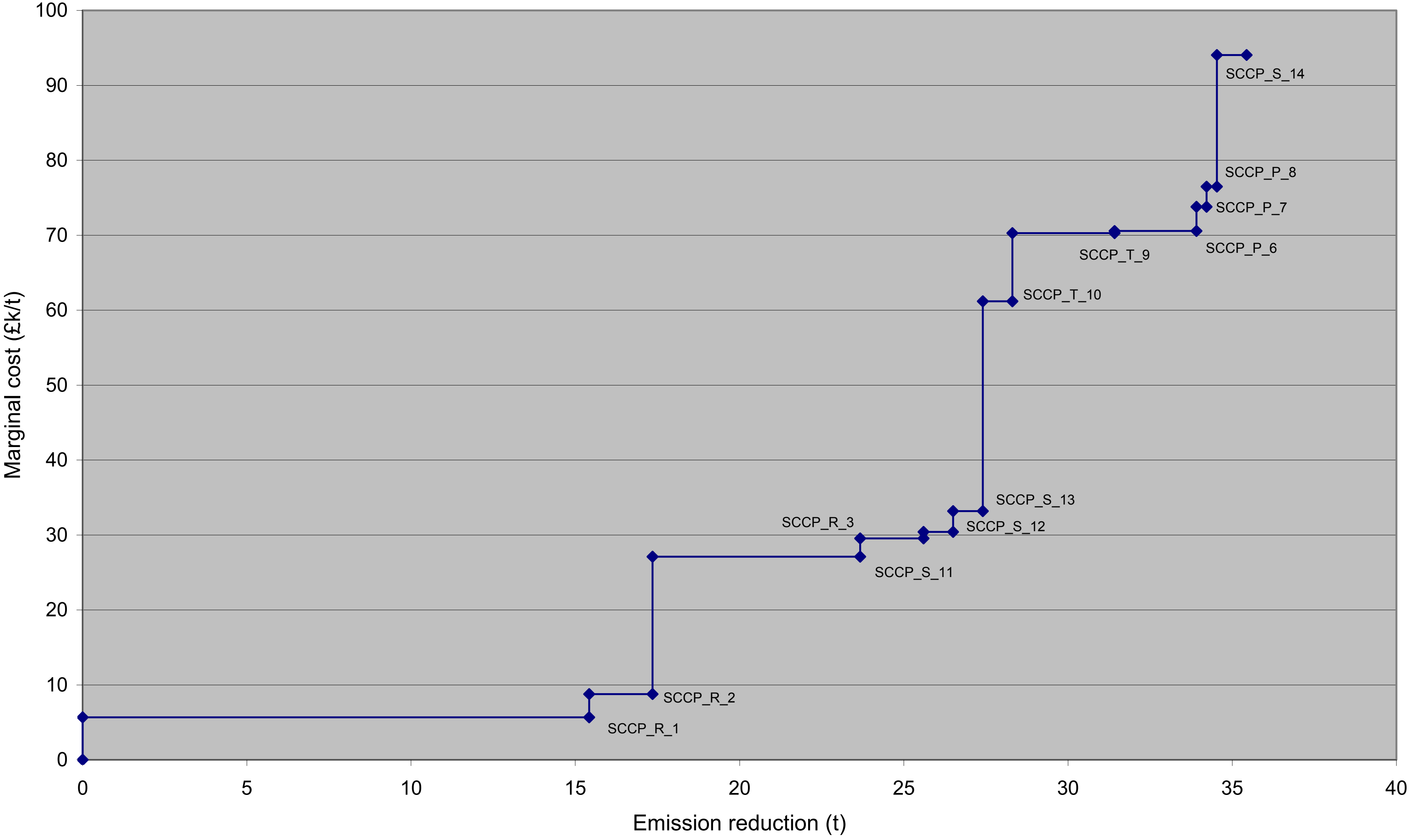


Figure 5.2 Graphical cost curve for SCCPs – type 2 (emission reduction and marginal cost)



5.3.4 Conclusions for SCCPs

The table below provides a summary of the extent to which it was possible to apply the draft method to SCCPs using the data available in the context of this study.

Table 5.3 Review of application of method to SCCPs

Step	Application to this substance
1. Set boundaries of cost curves	
1.1 Select substance(s) to be assessed	SCCPs.
1.2 Determine the appropriate geographical scale	EU-27 (although some data are older, prior to newer countries joining EU).
1.3 Determine the economic boundary of the analysis	Focused on SCCPs supply chain and use of alternatives.
1.4 Determine the reference year(s) for the analysis	Based on data from ECHA (2009c). Future reference year not taken given lack of data on likely changes in uses.
2. Quantify current and predicted future emissions	
2.1 Identify relevant lifecycle stages and uses of the substance	Done, based on ECHA (2009c).
2.2 Quantify current releases	Done, based on ECHA (2009c).
3. Existing and planned abatement techniques (the business-as-usual scenario)	
3.1 Identify and characterise existing and planned abatement techniques	Not done in any detail.
3.2 Estimate baseline (annual) environmental releases in reference year	Reference year was same as most recent year for which data were available in ECHA (2009c) report.
4. Identify and characterise possible future abatement measures	
4.1 Identify possible future measures to reduce emissions	Combination of substitution measures (for all uses) and emissions abatement for larger sources of emissions.
4.2 Characterise possible future measures	Based mainly on literature. Covered all issues (maximum feasible reduction, abatement efficiency, other lifecycle stages, costs and so on). Some assumptions were required.
5. Develop cost curves	
5.1 Develop spreadsheet (or other) model	Included in attached spreadsheet.
5.2 Estimate maximum potential emission reduction for each measure	Included in attached spreadsheet.
5.3 Estimate equivalent annual cost of each measure	Included in attached spreadsheet.
5.4 Initial ranking based on cost-effectiveness	Included in attached spreadsheet.
5.5 Determine interactions of measures	Included in attached spreadsheet and described above.
5.6 Calculate total emissions abated and total cost for each measure in order of expected preferential uptake	Included in attached spreadsheet.
5.7 Present results in order of preferential (most cost-effective) uptake	See cost curve output above.

6 Case study 2 – deca-BDE

6.1 Uses and releases

6.1.1 Lifecycle stages and use of the substance

Information on uses and releases is based on EU-level risk assessment reports, as well as various other assessments to examine potential risk management measures for deca-BDE.

Worldwide in 2005 there were four manufacturers of deca-BDE (Lowell Center, 2005). Deca-BDE is no longer manufactured in the EU with the last production site ceasing operation in 1999 (European Commission, 2002). Therefore the EU is entirely reliant on imports, with estimates of the total usage presented in the table below[11].

Table 6.1 Uses of deca-BDE

Data source	Total deca-BDE imported/ consumed in EU (tonnes)	Percentage used in plastics[1]	Percentage used in textiles[1]
EU RAR (2002)	8,210	82 (6,710)	18 (1,500)[2]
Defra (2003)	8,300	70 (5,800)	30 (2,500)[3]

[1] Tonnages presented in brackets

[2] 1,200 tonnes consumed in the UK, 300 tonnes in rest of EU.

[3] 1,250 tonnes consumed in the UK, 1,250 tonnes in rest of EU. Consumption estimate for UK excludes any imports of formulations and of backcoated materials used in the textile industry.

The table above indicates that the total estimates of quantities consumed at an EU level are in agreement, but there are differences in the breakdown of use between plastics and textiles, the two key uses/applications of deca-BDE[12]. Work for Defra (2003) included consultation with EBFRIP (European Brominated Flame Retardant Industry Panel) and it was suggested that consumption of deca-BDE was increasing at that time. EBFRIP also indicated that around 30 per cent was used in the textile industry and expressed its opinion that the estimates in the 2002 risk assessment report (European Commission, 2002) were too low. These updated figures were included in an update to the environmental risk assessment (European Commission, 2004). Therefore, the latter figures were included in the cost curve analysis here.

Furthermore the total consumption estimates presented in the table above do not consider any additional imports of masterbatch and finished goods containing deca-BDE; Defra (2003) estimated approximately 1,300 tonnes per year of extra-EU imports of deca-BDE in products (including non-television consumer products, television sets and flame retarded polysterene) (Defra, 2003). The literature review did not uncover more recent information on current consumption levels of deca-BDE in the UK and EU (Environment Agency, 2009).

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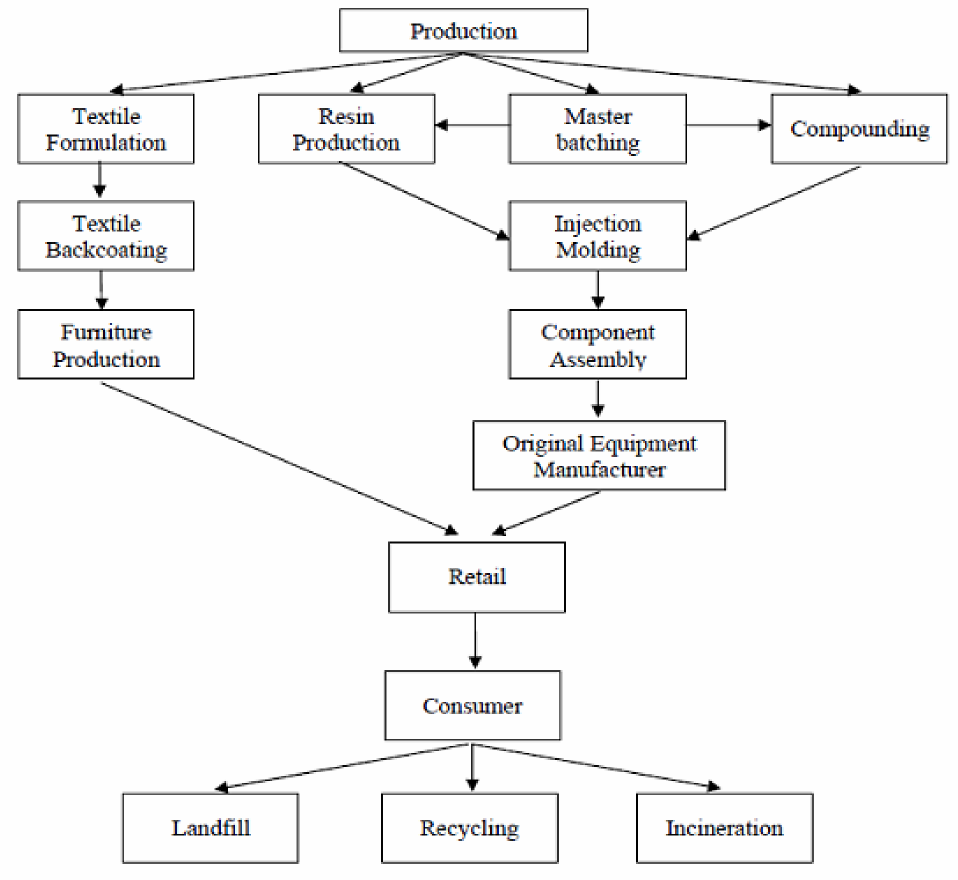
[11] Total production of deca-BDE has exceeded 60,000 metric tonnes worldwide, with over 40% of the use of deca-BDE occurring in North America (Illinois EPA, 2007).

[12] The remaining minor deca-BDE applications include rubber products, wire and cable, and uses in paper and mineral wool (Illinois Environmental Protection Agency, 2006).

Deca-BDE is used as an *additive* flame retardant in the plastics and textiles industries (it is physically combined with the material being treated, rather than chemically combined as is the case with reactive flame retardants). Additive flame retardants are more easily released to the environment compared to reactive ones.

According to a progress report *The Voluntary Emissions Control Action Programme for the brominated flame retardant deca-BDE*, the textile and plastics industries in the UK, France, Germany, Italy, Belgium and the Netherlands are responsible for more than 95 per cent of the total deca-BDE consumption in the EU (Danish EPA, 2006). The figure below presents the lifecycle of deca-BDE from production to disposal of end products.



Source: European Union 2004

Figure 6.1 Lifecycle from production to disposal of deca-BDE (European Commission, 2004)

In plastics the major use of deca-BDE is in electrical and electronic equipment (EEE) at loadings of 10-15 per cent weight in polymers. It is always used in conjunction with antimony trioxide. The major application for deca-BDE has historically been in high impact polystyrene (HIPS) with other less predominant applications including polypropylene (PP), acetate copolymers and styrenic rubbers (European Commission, 2002; Defra, 2003). From the literature review it was not possible to obtain a breakdown of the amounts of deca-BDE used in each plastic application.

The table below presents the estimated deca-BDE compounder and masterbatch activities in 2002 for the EU (Defra, 2003). The numbers of companies presented below are those that are/were members of APME[13], and it should be noted that only a limited number of compounders and masterbatchers are members of APME. Therefore the numbers presented are an underestimate of the true situation. The table also shows that the majority of companies are small/medium sized enterprises (SMEs).

Table 6.2 Number of EU compounders and masterbatchers (Defra, 2003)[1]

Country	Number of companies	Number of SMEs
Benelux [2]	4	3
France	22	19
Germany	10	7
Italy	23	21
Scandinavia	1	1
UK	4	4
Total	66	57

[1] The data do not include compounding for internal (in-house) use.
[2] Belgium, Netherlands and Luxembourg.

In textiles, deca-BDE is widely used for flame retarding polypropylene drapery and upholstery fabric (includes mattresses, drapery, commercial upholstered furniture and transportation (automotive and airplane) industries). Defra (2003) indicates the following breakdown of textiles applications in the UK (and it is assumed therein to be similar to other EU countries):

- 80 per cent on upholstery;
- 15 per cent on blinds;
- 5 per cent on other uses.

The UK is a major player in using deca-BDE for textiles and upholstery (due to its domestic fire safety legislation) and the industry can be split into three areas (European Commission, 2002):

- compounders (formulators), who mix and manufacture the flame retardant formulation;
- finishers, who apply the flame retardant coating to the fabric;
- self compounders, who both mix their own flame retardant formulation and apply it to the fabric.

In the UK, there are thought to be three or four major compounders/self compounders and three or four smaller ones. Two major compounders are thought to be in Germany along with three or four importers of flame retardant formulations into the UK. For the finishers, there are believed to be four large contract coaters and around six smaller ones in the UK (EC, 2002). Other countries reported as using deca-BDE in textiles are France, Belgium, Italy and Spain. Across the EU a total of 40 textiles finishers has been estimated[14] (European Commission, 2002).

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[13] Association of Plastics Manufacturers in Europe (http://www.plasticseurope.org/)

[14] 20-30 textile finishers in the EU apart from UK and Germany (European Commission, 2002)

6.1.2 Environmental releases

The European Risk Assessment Report (2002 and 2004) provides information on estimated releases of deca-BDE to the environment; these are presented at a site, regional and continental level. Estimated releases at an EU level were calculated by adding regional and continental modelling results. The following table presents a summary of the releases to each environmental medium based on the updated data from 2004.

Table 6.3 Releases of deca-BDE to the environment at an EU level (based on EC, 2002 and 2004) (tonnes)

Lifecycle stage/use	Activity	Air	Direct to surface water	Waste water	To soil	Total relevant releases
Manufacture						
Polymers	Handling raw materials					
	Compounding and conversion	0.08		0.01		0.09
	Service life	0.001	0.04		0.11	0.14
	Waste remaining in environment	0.004				0.004
	Disposal					
Textiles	Compounding	0.002		0.08		0.08
	Application	0.002		0.08		0.09
	Washing	0.03				0.03
	Waste remaining in the environment	0.05	12.45		37.50	50.00
	Disposal					
Total		**0.17**	**12.49**	**0.17**	**37.61**	**50.43**

[1] No emissions from manufacture or from handling of raw materials (polymers) are reported.
[2] Dust emissions are assumed to quickly settle within the facility and losses will be solid waste or waste water ultimately.
[3] Where ranges of emissions are given, the average has been quoted.
[4] Estimates for 'waste remaining in the environment' are subject to significant uncertainty.

From the above tables we deduce that:

- **Polymers** account for a relatively small amount of the deca-BDE released at an EU level at around 0.25 tonnes (based on the figures in EC, 2004).
- **Textiles** account for the vast majority of releases, representing around 50 tonnes per year (EC, 2004). The majority of these releases arise from particulate losses during disposal.

The emission estimates presented above are significantly lower than those in the original risk assessment report, in which total emissions were estimated to be over 600 tonnes, with a further 7,000 tonnes sent to landfill/incineration.

With regards to releases to different media, the following points can be made:

- **For air/dust vapour releases**: the release of deca-DBE in air/dust vapour is very small compared to the total volume released to the environment.
- **For waste water via WWTP releases**: the release of the substance to the environment via this route is also small compared to the total volume released.

- **For direct to surface water releases**: the release of the substance to the environment via this route is around one quarter of the total emissions, mainly related to release from disposal/particulate loss.
- **For industrial/urban soil release**: the release of the substance to the environment via this route is small for most lifecycle stages but is the single biggest contributor of releases from textiles (this relates to disposal losses).

6.2 Current and planned abatement measures

Deca-BDE is no longer permitted to be used in EEE in Europe (from 30 June 2008) under the RoHS Directive (Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment), although substantial stocks are present in treated articles that remain in circulation in society, and it still has a major use in textiles (Environment Agency, 2009). This ban clearly affects the future consumption of deca-BDE in the UK and the EU, although a substantial amount of deca-BDE will remain in existing EEE until disposal. The requirements of the RoHS Directive may also have implications for the recycling of plastics containing deca-BDE, as any recycled plastic used in new electrical and electronic equipment will need to comply with the requirements of the Directive. Therefore the main ongoing European use would appear to be for textile applications and in some polymer types not associated with electronic equipment (such as hot-melt adhesives), although the amounts are likely to be small (European Commission, 2002)[15].

The major suppliers of deca-BDE to the US market have recently agreed to phase out production, import and sales of deca-BDE for most uses by the end of 2013 (US EPA, 2010). This voluntary action followed restrictions in some US states[16].

EEE manufacturers have phased out, or plan to phase out, the use of deca-BDE, with a number of drivers for this change including: legislation (such as WEEE/RoHS), customers (such as green public procurement), recyclers, shareholders, employees, standardisation organisations (such as eco-design and Environmental Product Declarations), non-governmental organisations, media, eco-labelling (EU Flower, German Blue Angel, Nordic Swan, TCO) and competition (Danish EPA, 2006).

The manufacturing industry also set up a Voluntary Emissions Control and reduction Action Programme (VECAP) in 2004, with the approval of Member State authorities to promote new codes of good practice for the use of deca-BDE in the plastics and textile industries. The aim was to improve emission control for industrial point sources. The Environment Agency (2009) showed that there was little or no evidence of a decline in levels in any of the media sampled, suggesting that the VECAP has not made any substantial immediate impact on general levels of deca-BDE in the environment, although it may have prevented further increases (it has been effective at reducing the emissions from certain point sources). In addition, substantial stocks of the substance are present in treated articles that are still in use (which may be increasing year on year), and the VECAP was not designed to address emissions from this source (such as dust arising from textile wear).

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[15] Most major consumer electronics manufacturers have announced they have phased out, or plan to phase out, the use of deca-BDE (Lowell Center, 2005). These manufacturers include: Apple, Brother, Compaq, Daikin, Dell, IBM, Matsushita, Samsung, Sharp, Sony, and Xerox.

[16] www.maine.gov/legis/housedems/news/deca_bill_signed_into_law%20.htm.

6.3 Possible future abatement measures

6.3.1 Information sources

Based on the data presented above, it is evident that the major historical use of deca-BDE (in electrical and electronic equipment) should have been phased out, although the substance will remain in articles already in circulation for some time.

As such, the historical data on uses and releases (from 2004) were used as the basis for developing the cost curves, allowing more uses and measures to be taken into account (and hence to test the potential for use of the cost curves). In any case, the most recent year for which data on uses and environmental releases exist predate the requirements of the RoHS Directive.

Some information is available on the likely costs of using alternative substances but little or none on costs and abatement potential for other emission reduction measures, particularly abatement of emissions from industrial sources. Whilst these constitute a relatively small share of total emissions, to illustrate cost curves with a reasonable number of different measures to reduce emissions, abatement was estimated based on generic literature sources (such as measures applicable to a range of sources).

6.3.2 Measures included in the cost curve

The following measures were assessed in developing the cost curve for deca-BDE:

- Replacement of deca-BDE with alternatives in polymers, in particular replacement with other brominated flame retardants in HIPS to fire safety standard UK 94 V-0 (measure reference Deca_P_1), replacement with other brominated flame retardants in HIPS to fire safety standard UK 94 V-1 (Deca_P_2), and replacement with halogen-free flame retardant (Deca_P_3).
- Additional waste water treatment for polymer compounding and conversion (Deca_P_4).
- Thermal oxidation of emissions to air for polymer compounding and conversion (Deca_P_5).
- Replacement of deca-BDE with phosphorus flame retardant in textiles (Deca_T_6).
- Additional waste water treatment for textile compounding and application (Deca_T_7).

Appendix C of this report provides details of the data sources and assumptions used in assessing the emission reduction potential and costs associated with each measure.

6.3.3 Cost curve for deca-BDE

The table below provides a summary of the key data on each of the measures for inclusion in the cost curve. Further details are included in the spreadsheet[17]. The cost curve is presented graphically in two formats: the first is based on emission remaining and total cost and the second on emission abated and marginal cost.

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[17] Microsoft Excel® spreadsheets that support the examples are available on request from the Environment Agency's project manager.

Table 6.4 Summary of cost curve data for deca-BDE

Measure	Single-measure cost (£)	Single-measure emission reduction (t)	Cost-effectiveness (£/t)	Incremental cost (£)	Incremental emission reduction (t)	Incremental cost-effectiveness (£/t)	Notes
Deca_T_6	7,248,000	50.20	144,000	7,248,000	50.195	144,000	Alternative to Deca_T_7
Deca_P_5	1,817,000	0.08	22,659,000	1,817,000	0.080	22,659,000	Alternative to Deca_P_1, Deca_P_2 and Deca_P_3
Deca_P_2	2,417,000	0.08	30,887,000	2,417,000	0.052	46,915,000	Alternative to Deca_P_4 and Deca_P_5
Deca_P_1	5,639,000	0.08	72,071,000	5,639,000	0.052	109,469,000	Alternative to Deca_P_4 and Deca_P_5
Deca_P_3	15,306,000	0.08	195,620,000	15,306,000	0.052	297,131,000	Alternative to Deca_P_4 and Deca_P_5

All data on costs and emission reductions are at EU level. Incremental costs and emission reductions are not necessarily the same as single measure values as they take into account the prior application of more cost-effective measures. Measure “Deca_T_7” (WWTP for textiles) is not included because it does not include any additional abatement above measure Deca_T_6 (replacement in textiles). Measure ‘Deca_P_4’ (additional WWTP for polymers) is not included because it does not include additional abatement above Deca_P_5 (thermal oxidation) and Deca_P_2, Deca_P_1 and Deca_P_3 (use of alternatives).

Figure 6.2 Graphical cost curve for deca-BDE – type 1 (emission remaining and total cost)

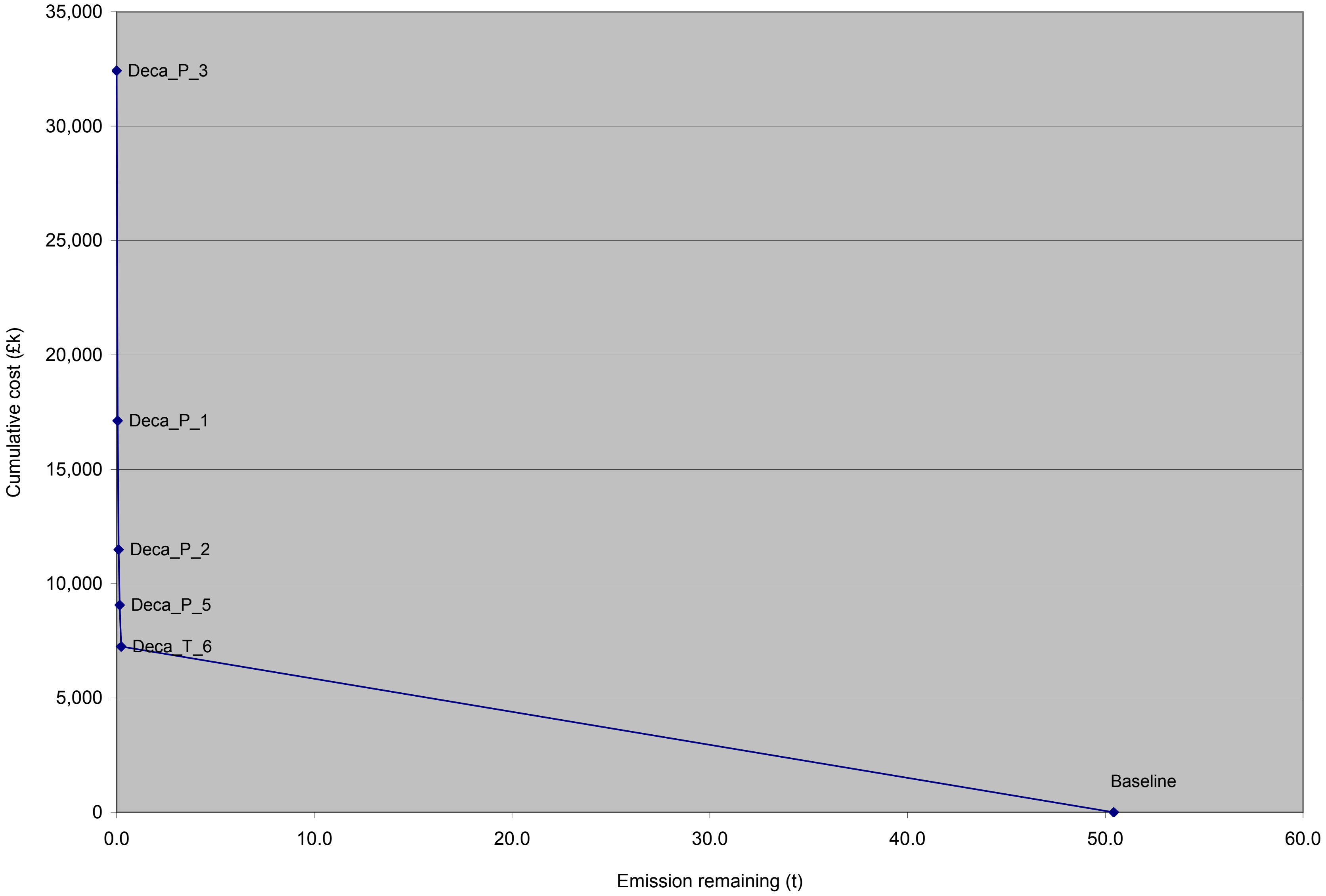
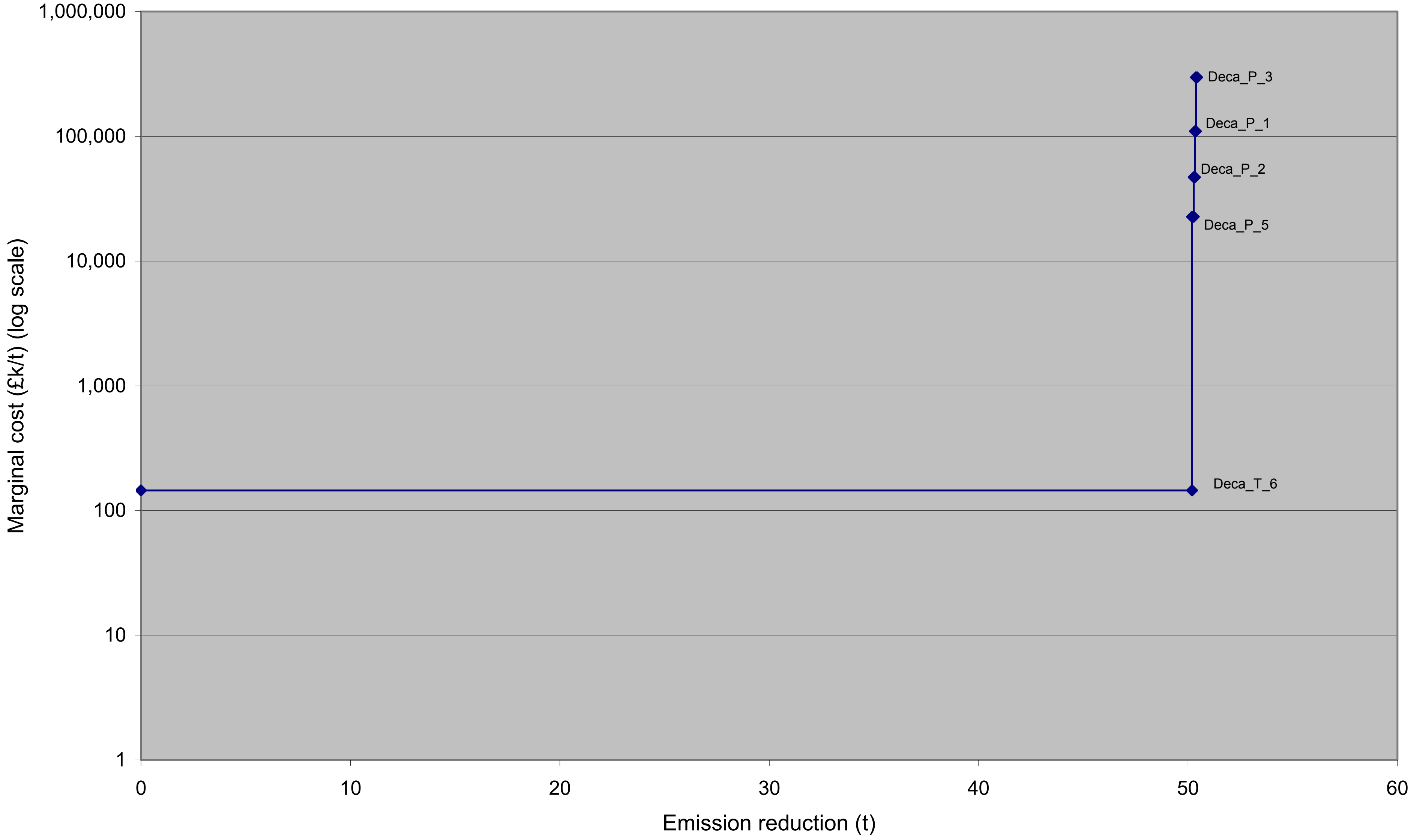


Figure 6.3 Graphical cost curve for deca-BDE – type 2 (emission reduction and marginal cost)



6.3.4 Conclusions for deca-BDE

The table below provides a summary of the extent to which it was possible to apply the draft method to deca-BDE using the data available in the context of this study.

Table 6.5 Review of application of method to deca-BDE

Step	Application to this substance
1. Set boundaries of the cost curves	
1.1 Select substance(s) to be assessed	Deca-BDE.
1.2 Determine the appropriate geographical scale	EU-27 (although some data are older, prior to newer countries joining EU).
1.3 Determine the economic boundary of the analysis	Focused on deca-BDE supply chain and use of alternatives.
1.4 Determine the reference year(s) for the analysis	Based on data from EC risk assessment (2004) as latest comparable data for use and releases. Future reference year not taken given lack of data on likely changes in use/emissions. Uncertainty given that use in electronic and electrical equipment will now have significantly reduced.
2. Quantify current and predicted future emissions	
2.1 Identify relevant lifecycle stages and uses of the substance	Done, based on European Commission (2002, 2004).
2.2 Quantify current releases	Done, based on European Commission (2002, 2004). Data are from 2004.
3. Existing and planned abatement techniques (the business-as-usual scenario)	
3.1 Identify and characterise existing and planned abatement techniques	Not done in any detail.
3.2 Estimate baseline (annual) environmental releases in reference year	Reference year was same as most recent year for which data were available in EC risk assessment report.
4. Identify and characterise possible future abatement measures	
4.1 Identify possible future measures to reduce emissions	Combination of substitution measures (for all uses) and emissions abatement for the two main sources of emissions.
4.2 Characterise possible future measures	Based mainly on literature sources. Covered all issues (maximum feasible reduction, abatement efficiency, other life-cycle stages, costs and so on). Assumptions were required on e.g. per cent of use for which different substitutes would be used (no data in the literature).
5. Develop cost curves	
5.1 Develop spreadsheet (or other) model	Included in attached spreadsheet.
5.2 Estimate maximum potential emission reduction for each measure	Included in attached spreadsheet.
5.3 Estimate equivalent annual cost of each measure	Included in attached spreadsheet.
5.4 Initial ranking based on cost-effectiveness	Included in attached spreadsheet.

Step	Application to this substance
5.5 Determine interactions of measures	Included in attached spreadsheet and described above.
5.6 Calculate total emissions abated and total cost for each measure in order of expected preferential uptake	Included in attached spreadsheet.
5.7 Present results in order of preferential (most cost-effective) uptake	See cost curve output above.

7 Case study 3 – DEHP

7.1 Uses and releases

7.1.1 Lifecycle stages and use of the substance

7.1.1.1 Quantity manufactured and number of manufacturers in EU-27

Much of the information presented in this section is based on data for EU-level risk assessments and a risk reduction strategy, as well as a report prepared for ECHA.

While the manufactured amount of di(2-ethylhexyl) phthalate (DEHP) was relatively constant during the period 1979 to 1998 in Europe, over the last 10 years the manufacture of DEHP has decreased dramatically from 595,000 tonnes per year in the EU-15 in 1997 to 340,000 tonnes/year in 2007[18]. The drop is even more significant as the 1997 figure does not include production volumes in the 12 new Member States. Of the 340,000 tonnes of DEHP produced in 2007, 187,000 were produced in Western Europe corresponding to around one-third of the 1997 production levels.

In 2007 there were seven DEHP manufacturers in the EU, located in France, Germany, Sweden, Italy, Poland, Romania and the Czech Republic.

7.1.1.2 Imports and exports of DEHP

The EU-27 is a net exporter of DEHP on its own as well as of DEHP in preparations and in articles, as shown in the table below.

Table 7.1 Extra-EU import and export of DEHP, preparations and articles containing DEHP in 2007

Name	2007 Import, tonnes/year	2007 Export, tonnes/year
DEHP	4,479	54,522
DEHP in preparations	~1,000	~10,000
DEHP in articles	40,000	37,000

Source: ECHA (2009a).

7.1.1.3 Quantity used in different formulation stages and number of companies

DEHP is used in a large number of preparations including adhesives, sealants, rubber, lacquers, paints, and printing inks.

The total estimated volume of DEHP used in formulation was 61,000 tonnes/year in 2007 which is a significant decrease from the equivalent figure in 1999, when almost 100,000 tonnes/year were used. No information is available on the number of sites.

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[18] ECHA (2009a, 2009d); Oehlmann *et al*. (2008).

Table 7.2 DEHP use for formulation in 2007

Name	Amount 2007, tonnes/year	Percentage of total, 2007	Number of sites (1999)
Polymeric formulation (production of semi-finished products):			
Compounding by extrusion	52,000	84	83
Non-polymeric formulation (manufacture of products):			
Formulation of adhesives/sealant, rubber	7,000	11	
Formulation of lacquers and paint	900	1	
Formulation of printing ink	1,000	2	
Formulation of ceramics	20	0	
Total formulation	61,000	99	

Source: ECHA (2009a).

In 2007 about 283,000 tonnes/year of DEHP were used in a wide range of processing applications. These volumes have also decreased significantly since 1999. Extrusion of wire and cable, spread coating of coated fabric, wall and coil covering as well as calendering of film/sheet and coated products were the most notable processes that used DEHP.

Table 7.3 DEHP use for processing in 2007

Name	Amount 2007, tonnes/year	Per cent of total, 2007	Number of sites (1999)
Formulation and processing (at same site):			
Calendering of film/sheet and coated products	44,000	16	74
Calendering of flooring, roofing, wall covering	21,000	7	20
Extrusion of hose and profile	35,000	12	82
Extrusion of wire and cable	49,000	17	62
Spread coating of flooring	24,000	85	21
Spread coating of coated fabric, wall covering, coil coating, and so on	47,000	17	115
Car undercoating	4,000	1	nd
Slush/rotational moulding, dip coating	6,000	2	nd
Processing from compound			
Extrusion of cables, medical, and misc. products	21,000	7	nd
Injection moulding of misc. products	22,000	85	nd
Plastisol processing from compounds	900	0	nd
Non-polymeric, processing			
Adhesives/sealant	7,000	2	nd
Lacquers and paint	900	0	nd
Printing ink	1,000	0	nd
Production of ceramics	20		nd
Total processing (rounded)	283,000	97%	

Source: ECHA (2009a).

Information is available on the number of sites involved for some of these processes. Overall, a large number of sites in the EU are involved in the formulation and processing of DEHP, in particular into polymer (mainly PVC) products. While the exact number of sites is unknown it is assumed to be 500 to 1,000.

7.1.1.4 Number of user companies and extent of consumer use

DEHP is used in a large number of diverse articles and preparations, which are used ubiquitously in the EU; in particular, DEHP is widely used as a plasticizer in polymer products, mainly PVC. The content of DEHP in flexible polymer materials varies, but is often around 30 per cent (weight by weight or w/w).

There is a wide dispersive use of preparations and goods containing DEHP. The number of producers of end-products is relatively high, with a high number of actors representing different types of construction industries.

Table 7.4 Main end product uses of DEHP

Application	Uses of DEHP
Polymer	
Flooring	PVC flooring (with PVC surface) Carpets with PVC backcoating Cork with PVC topcoating or backcoating
Wall covering	
Roofing	
Film/sheet and coated products	Curtains, blinds, table linen, etc. Packaging Tape and self-adhesive foils Office supplies (ring binders, files, slip cases, etc.) Toys (swimming pools, rubber beach toy, beach balls, etc.) Medical bag/sheet devices Bottom sheets for hospitals
Wires and cables	
Hoses and profiles	Garden hoses and tubes Hoses and tubes in industry Profiles of windows and electrical products Medical tubing
Coated fabric	Upholstery and car seats (synthetic leather) Luggage Rainwear Tarpaulins Water beds
Moulded product	Footwear Adult toys (DEHP is not permitted in toys for children)
Car undercoating	
Non-polymer	
Adhesives	
Lacquers and paints	Printing inks Sealants (glass insulation, construction) Ceramics

Source: ECHA (2009a).

7.1.1.5 Quantities used in each application type

DEHP is one of a number of substances widely used as a plasticiser in PVC and other polymeric materials which are used in a range of products including flooring, wall coverings, roofing, cables, rainwear, toys, profiles, food contact applications and medical products such as blood bags and dialysis equipment. DEHP has historically been the most commonly used plasticiser. Among other properties, DEHP imparts to PVC flexibility, strength, optical clarity, and resistance to broad temperature variations.

In the non-PVC field, DEHP is used in detergents, industrial solvents, wetting agents or lubricating oils, such as for lacquers, colours or adhesives. It is also used in advanced ceramic materials for electronic and structural applications.

The net use of DEHP in the EU in 2007 is estimated at approximately 282,000 tonnes per year. Overall, about 97 per cent of DEHP is used as plasticiser in polymers, mainly PVC and the remaining three per cent in other non-polymer applications.

Table 7.5 Estimated DEHP tonnage in end-products (including manufacturing, import and export)

Areas of application	End-product use, tonnes/year	Percentage of total use
Indoor uses		
Polymer applications:		
Flooring	30,200	10.6
Wall covering	10,100	3.5
Film/sheet and coated products made by calendering	41,200	14.5
Wires and cables	52,600	18.5
Hoses and profiles	29,600	10.4
Coated fabric and other products from plastisol	31,800	11.2
Moulded product	5,000	1.8
Other polymer applications	20,100	7.1
Non-polymer applications:		
Adhesives and sealants	4,000	1.4
Lacquers and paints	500	0.2
Printing ink	1,000	0.4
Other non-polymeric	20	0.0
Outdoor uses		
Polymer applications:		
Calendered roofing material	600	0.2
Coil coated roofing material	3,000	1.1
Wire and cables - air	2,400	0.8
Wire and cables - soil	9,700	3.4
Coated fabric	12,800	4.5
Car undercoating	4,000	1.4
Hoses and profiles	3,700	1.3
Shoe soles	19,400	6.8
Non polymer applications:		
Lacquers and paints	400	0.1
Adhesives and sealant	3,300	1.2
Total end-product use (rounded)	282,000	100

Source: ECHA (2009a).

7.1.1.6 Quantity (including in articles) passing to different disposal and end of life routes

Approximately 195,000 tonnes were disposed of to landfill in 2007, 80,000 tonnes were incinerated and 7,000 tonnes disposed of through car shredding.

7.1.2 Environmental releases

The formulation and processing of DEHP into preparations and in particular into polymer (mainly PVC) products take place at a large number of sites in the EU. As DEHP is not chemically bound in preparations or articles, the potential for release into the environment with time and use and subsequent exposure is high, potentially causing significant environmental burdens.

Table 7.6 Releases of DEHP from manufacturing, formulation, processing, end products use and disposal in the EU in 2007

Name	Amount 2007, t/y	Emissions to air (t/y)	Emissions to soil (t/y)	Emissions to waste water (t/y)
EU manufacture of DEHP	341,000	1	4	220
Transportation of substance from manufacturing	345,479	0	0	29
Formulation	61,000	30	1	97
Processing	283,000	174	41	125
End-product uses, indoor	223,000	380	0	1,240
End-product uses, outdoor, non-abrasive leakages	33,000	30	3,980	500
End-product uses, outdoor, abrasive leakages	33,000	5	3,500	1,200
Disposal and recycling options	275,133	9	48	10
Total releases		**600**	**7,600**	**3,400**

Source: ECHA (2009a).

The main releases in 2007 were to soil and waste water. The use of end-products (articles) gives rise to the largest releases to the environment, with washing of flooring, releases from underground cables and abrasive releases and pieces lost in the environment as the largest single sources. In addition, emissions from non-abrasive releases (solid wastes) in 2007 were 275,000 tonnes/year.

7.2 Current and planned abatement measures

7.2.1 Specific abatement measures already applied

A wide range of regulations controls and restricts manufacturing and use of DEHP. The key relevant legislation includes those discussed below.

The REACH regulation (Regulation No 1907/2006): DEHP is defined as a Substance of Very High Concern (SVHC) and may require authorisation for use in the future.

The Water Framework Directive (WFD, 2000/60/EC) contains a list of 33 priority substances including DEHP with the aim to prevent deterioration of surface and ground water. The proposed controls aim at progressive reduction of discharges, emissions and losses and for Priority *Hazardous* Substances cessation or phasing out of discharges, emissions and losses is required within 20 years. EQS have also been set.

The Integrated Pollution Prevention and Control (IPPC) Directive (2008/1/EC): As DEHP is an oxygen-containing hydrocarbon produced in substantial amounts, it is covered by this directive. As it may also affect reproduction, it is part of Annex III. Overall the directive affects large installations producing DEHP but not the downstream users that do compounding and manufacturing of articles such as floorings. The provisions in the IPPC directive are therefore only expected to limit DEHP emissions for some lifecycle stages. At present, no other legal measures are aimed at minimising emissions from installations producing articles containing DEHP at the EU-level.

Directive 2009/48/EC on Toy Safety lays out rules on the use and restriction of CMRs (carcinogenic, mutagenic and reprotoxic chemicals) in toys. DEHP is one of the three restricted phthalates (classified as CMR substances) covered by the Phthalates Directive and is therefore banned under the Toy Safety Directive if present above the 0.1 per cent threshold. The directive on general product safety (92/59/EEC) is also relevant to DEHP.

Directive 2005/84/EC of 14 December 2005 restricts the use of certain phthalates in toys and childcare articles. Article 2 provides for the re-evaluation of the measures by January 2010. The directive prohibits DEHP use in all toys and childcare articles. As they are all classified as CMR substances, their use would anyway be now prohibited under the new Toy Safety Directive. Directive 2005/84/EC also states that "*In line with the Commission Communication on the Precautionary Principle, the measures based on this principle should be subject to review in the light of new scientific information*". These restrictions are now regulated as part of Annex XVII of the REACH regulation (Regulation (EC) 1907/2006).

The directive on restrictions on the marketing and use of certain substances and preparations (76/769/EEC). As DEHP is a CMR, its sale to consumers directly is restricted. Therefore, DEHP can only be supplied to consumers at low concentrations in mixtures or in end-products (articles).

The directive on plastic materials and articles intended to come in contact with foodstuffs (90/128/EEC). The hydrophobic nature of DEHP causes it to migrate from plastics coming in contact with fatty foodstuffs. This Directive places limits on migration from such materials into foods.

The directive on medical devices (93/42/EEC). This directive secures safety and performance of medical devices, but leaves responsibility to the manufacturers and medical staff. As DEHP was widely used for softening tubes and delivering medical devices both flexibility and stability, some concerns arose regarding these uses. In many medical devices DEHP has been replaced voluntarily, but DEHP-containing devices are still used and available in the market.

The directive on the protection of the health and safety of workers from risks related to chemical agents at work (98/24/EEC). At an EU level no occupational exposure limits (OELs) have been established, but some have been introduced at a national level. This is valid especially for employees working in DEHP and polymer production. All companies working with hazardous substances should conduct a risk assessment to assure workers' safety and health. Meeting OELs is one of a number of risk management options identified under this directive.

The directive on pregnant workers and workers who have recently given birth or are breastfeeding (92/85/EEC). This places more stringent requirements than the directive above as concerns pregnant and other relevant workers, as DEHP is a Category 1B reprotoxin (under the CLP Regulation).

7.2.2 Baseline environmental releases in reference year

Information is available on the current releases of DEHP (up to 2007). However no quantitative estimates were identified in the literature reviewed as part of this study on the impact of the abatement measures in place or planned, with regard to future emissions of the substance. An appropriate reference year, therefore, would be 2007.

7.3 Possible future abatement measures

7.3.1 Information sources

Based on the information reviewed above, a number of potential further measures are possible. Measures identified in the literature reviewed include use of phthalate and non-phthalate alternative substances or materials, and end-of-pipe controls, such as at waste water treatment plants.

In some cases, it was necessary to use more generic information (such as information applicable to waste water treatment in general) to provide estimates of the likely scale, costs and emissions abatement of possible measures. Therefore, use was made of documentation such as IPPC BREF documents and a number of studies in the context of the Water Framework Directive, as referred to below.

7.3.2 Measures included in the cost curve

The following measures were assessed in developing the cost curve for DEHP:

- Additional advanced (tertiary) water treatment for manufacture of DEHP, including membrane filtration (measure reference BBAU1), ozone oxidation (BBAU2) and activated carbon (BBAU3).
- Additional waste gas treatment for manufacture of DEHP, including biofiltration (BBAU4), coolant condensation (BBAU5) and thermal oxidation (BBAU6).
- Additional advanced (tertiary) water treatment for formulation and processing, including membrane filtration (BBAU7), ozone oxidation (BBAU8) and activated carbon (BBAU9).
- Additional waste gas treatment for formulation and processing, including biofiltration (BBAU10), coolant condensation (BBAU11) and thermal oxidation (BBAU12).
- Additional advanced (tertiary) water treatment at public WWTP to treat indoor and outdoor public use, including membrane filtration (measure reference BBAU13), ozone oxidation (BBAU14) and activated carbon (BBAU15).
- Substitution of DEHP in use in film/sheet and coated products made by calendaring with DIDP (BBAU16).
- Substitution of DEHP in hoses and profiles with DINP (BBAU17).
- Substitution of DEHP in flooring and wall coating with DINP (BBAU18).
- Substitution of DEHP in coil coated roofing with DIDP (BBAU19).
- Substitution of DEHP in wires and cables with DINP (BBAU20).
- Substitution of DEHP in footwear with DEHT (BBAU21).
- Substitution of DEHP in coated fabric with DEHT (BBAU22).
- Substitution of DEHP in lacquers and paints with DINCH (BBAU23).

Appendix D of this report provides details on the data sources and assumptions used in assessing the emission reduction potential and costs associated with each measure.

7.3.3 Cost curve for DEHP

The table below provides a summary of the key data on each of the measures for inclusion in the cost curve. Further details are included in the spreadsheet[19].

The cost curve is presented graphically in two formats: the first is based on emission remaining and total cost and the second on emission abated and marginal cost. In this case, a third figure is presented, based on the second type but with a logarithmic scale for the marginal costs (to allow the results to be seen more readily).

The cost curve excludes various measures (amongst those listed in the previous section). For example, treatment of waste water to control releases from the use phase is assumed not to be applied because substitution would be a more cost-effective means of reducing emissions. Furthermore, whilst there are several cases where different abatement techniques could be applied to a particular source (such as BBAU1, BBAU2 and BBAU3), in this case – though this need not always be so – the most cost-effective measure is also that which is estimated to abate the most emissions (for example, BBAU1 abates 94 per cent of emissions). This means that the next most cost-effective measure is not included in the cost curve (BBAU3 at 60 per cent abatement) and nor is the least cost-effective of the three (BBAU2 at 80 per cent).

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[19] Microsoft Excel® spreadsheets that support the examples are available on request from the Environment Agency's project manager.

Table 7.7 Summary of cost curve data for DEHP

Measure	Single-measure cost (£)	Single-measure emission reduction (t)	Cost-effectiveness (£/t)	Incremental cost (£)	Incremental emission reduction (t)	Incremental cost-effectiveness (£/t)	Notes
BBAU5	13,000	198	70	13,000	198	70	Cannot be applied with BBAU 4&6. Cannot be applied partially with BBAU16-23
BBAU19	660,000	1,667	400	660,000	1,667	400	Partially additional to BBAU1-15; included
BBAU21	1,752,000	2,022	870	1,752,000	2,022	870	Partially additional to BBAU1-15; included
BBAU23	278,000	258	1,080	278,000	258	1,080	Partially additional to BBAU1-15; included
BBAU1	403,000	207	1,950	403,000	207	1,950	Cannot be applied with BBAU 2&3. Cannot be applied partially with BBAU16-23
BBAU20	7,915,000	3,992	1,980	7,915,000	3,992	1,980	Partially additional to BBAU1-15; included
BBAU22	4,029,000	899	4,480	4,029,000	899	4,480	Partially additional to BBAU1-15; included
BBAU18	4,930,000	1,067	4,620	4,930,000	1,067	4,620	Partially additional to BBAU1-15; included
BBAU11	1,524,000	200	7,620	1,524,000	200	7,620	Cannot be applied with BBAU 10&12. Cannot be applied partially with BBAU16-23
BBAU17	1,855,000	181	10,230	1,855,000	181	10,230	Partially additional to BBAU1-15; included
BBAU16	9,196,000	300	30,670	9,196,000	300	30,670	Partially additional to BBAU1-15; included
BBAU7	46,101,000	209	220,720	46,101,000	209	220,720	Cannot be applied with BBAU 8&9. Cannot be applied partially with BBAU16-23

All data on costs and emission reductions are at EU level. Incremental costs and emission reductions are not necessarily the same as single measure values as they take into account the prior application of more cost-effective measures.

The cost curve does not include the following measures because they do not provide additional abatement beyond other measures (and are less cost-effective): BBAU4, BBAU6, BBAU10, BBAU3, BBAU12, BBAU2, BBAU13, BBAU9, BBAU15, BBAU8, BBAU14.

Figure 7.1 Graphical cost curve for DEHP – type 1 (emissions remaining and total cost)

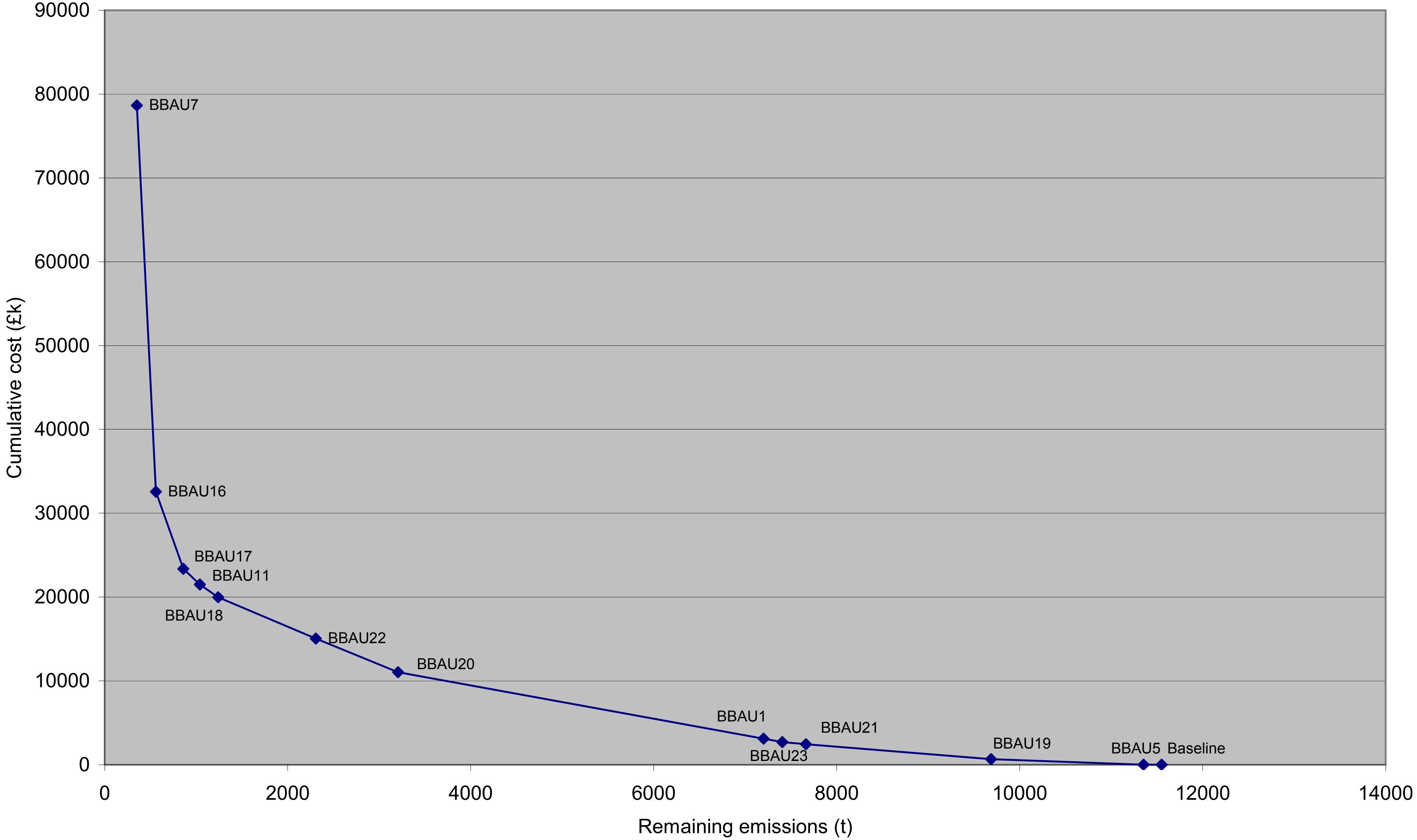


Figure 7.2 Graphical cost curve for DEHP – type 2 (emissions removed and marginal cost with linear axes)

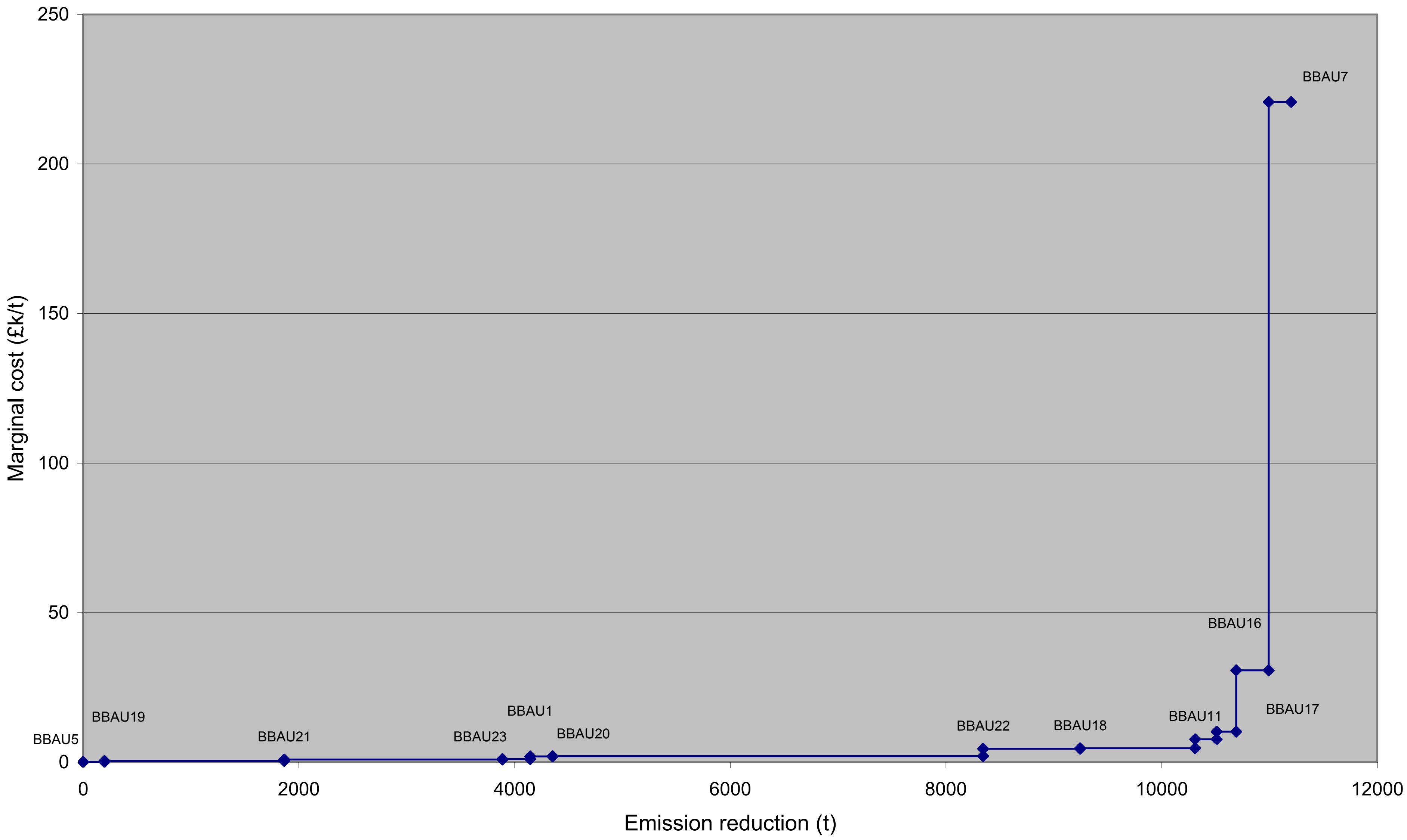
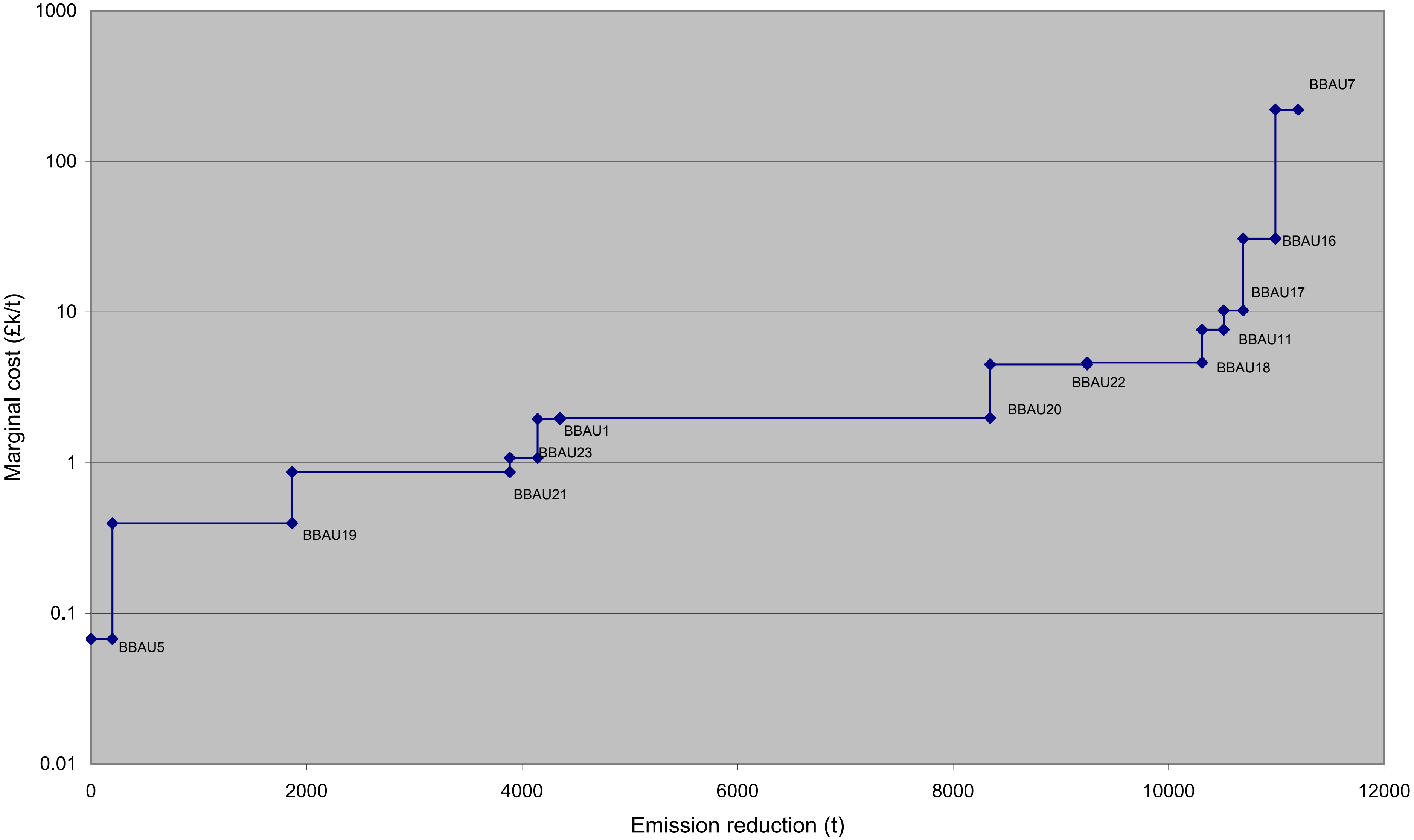


Figure 7.3 Graphical cost curve for DEHP – type 2 (emissions removed and marginal cost with logarithmic cost axis)



7.3.4 Conclusions for DEHP

The table below provides a summary of the extent to which it was possible to apply the draft method to DEHP using the data available in the context of this study.

Table 7.8 Review of application of method to DEHP

Step	Application to this substance
1. Set boundaries of cost curves	
1.1 Select substance(s) to be assessed	DEHP
1.2 Determine the appropriate geographical scale	EU-27
1.3 Determine the economic boundary of the analysis	Focused on DEHP production, formulation & processing, its use as well as use of substitute substances.
1.4 Determine the reference year(s) for the analysis	2007 (data available on uses, emissions). Future reference year not taken given lack of data on likely future changes in uses and emissions.
2. Quantify current and predicted future emissions	
2.1 Identify relevant lifecycle stages and uses of the substance	Done, ECHA (2009a)
2.2 Quantify current releases	Done, ECHA (2009a, d)
3. Existing and planned abatement techniques (the business as usual scenario)	
3.1 Identify and characterise existing and planned abatement techniques	Information is available on the relevant EC policy for DEHP but not at the scale of technical measures.
3.2 Estimate baseline (annual) environmental releases in reference year	Reference year was same as most recent year for which data were available: 2007.
4. Identify and characterise possible future abatement measures	
4.1 Identify possible future measures to reduce emissions	Combination of substitution measures (for all uses) and emissions abatement for larger sources of emissions including manufacturing, processing and use. European Commission (2009); ECHA (2009a, d); SOCOPSE (2009); Swedish Chemicals Inspectorate (2006).
4.2 Characterise possible future measures	Based mainly on literature sources. Covered list of measures, efficiency, costs. Assumptions were required on e.g. application rates, sometimes costs and efficiency. European Commission (2009); ECHA (2009a, d); SOCOPSE (2009); Swedish Chemicals Inspectorate (2006).
5. Develop cost curves	
5.1 Develop spreadsheet (or other) model	Included in attached spreadsheet.
5.2 Estimate maximum potential emission reduction for each measure	Included in attached spreadsheet.
5.3 Estimate equivalent annual cost of each measure	Included in attached spreadsheet.
5.4 Initial ranking based on cost-effectiveness	Included in attached spreadsheet.

Step	**Application to this substance**
5.5 Determine interactions of measures	Included in attached spreadsheet and described above.
5.6 Calculate total emissions abated and total cost for each measure in order of expected preferential uptake	Included in attached spreadsheet.
5.7 Present results in order of preferential (most cost-effective) uptake	See cost curve output above.

8 Conclusions and recommendations

8.1 Value of the method

This project comprised a pilot study to develop a method for estimating abatement costs to reduce emissions of chemicals, and to test the method with selected substances of very high concern.

The work involved developing cost curves for three example chemicals, based on information readily available in the literature, rather than through extensive consultation with industry and generation of additional primary data.

The work was closely followed by a project board who provided comments on interim and draft outputs. A draft of this report was also presented and discussed at a workshop on "abatement costs of chemicals" organised by the European Chemicals Agency on 6 October 2010[20]. This report has been modified to take into account comments received at that workshop.

For each of the three substances, cost curves were developed to include different types of measures, specifically measures that would reduce emissions through substitution of the chemical with alternatives and also measures that could reduce emissions through use of additional abatement equipment.

These cost curves illustrate the costs and relative emissions reductions of measures to substitute chemicals and measures to abate sources of emissions. This is likely to be of particular use in determining the best means of regulating such chemicals (such as subjecting chemicals to authorisation under REACH).

The curves also show the relative costs and emission reductions of substituting a substance in different areas of use, highlighting the fact that there can be significant differences between costs of substitution per unit of *use* in different applications and costs of substitution per unit of *emission* from those applications. For example, with deca-BDE, substitution in polymers is much more cost-effective than substitution in textiles in terms of use but much less cost-effective in terms of emissions abated.

The relative costs, in terms of £/t of emission abated, of reducing emissions for different substances is also elucidated. This is of particular relevance for substances where it is (currently) not straightforward to understand the benefits of reducing emissions in a quantitative sense, such as for PBT substances. For example, in determining whether it would be preferable to abate emissions of substance X or substance Y, both PBT substances, the relative costs of abatement could be a useful factor in the decision-making process, where it is not simple to determine the environmental benefits of abating one substance over the other.

This approach therefore seems to have benefits which could aid decision-making on regulation of chemicals, particularly at the current time when there is no fully developed method for estimating the environmental benefits of abating emissions of chemicals. This method could help in prioritising regulatory and other action, as well as understanding the impacts of new legislative requirements.

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[20] The presentations and workshop conclusions are available on ECHA's website at: http://echa.europa.eu/reach/sea/sea_workshop_20101006_en.asp.

Whilst the three chemicals considered each have differences in their environmental hazards and risks, producing cost curves in the form derived here also allows the costs and abatement potential to be compared for different measures and different pollutants at the same time. By way of illustration, Figure 8.1 shows a combined cost curve for the three substances, including the measures for each of these. Such an approach could aid policy-making in terms of deciding which substances and which uses to prioritise for regulatory control (for example). This figure highlights significant differences in cost-effectiveness in reducing emissions of each of the pollutants, as well as differences amongst the measures for each substance.

However, reducing emissions (or use) of one substance by, for example, one kilogram is unlikely to have the same environmental benefit as reducing one kilogram of emissions (or use) of another chemical. Unless there is a good reason why chemicals should be treated equally in this context, more sophisticated approaches are likely to be required in order to understand the different benefits in controlling different chemicals.

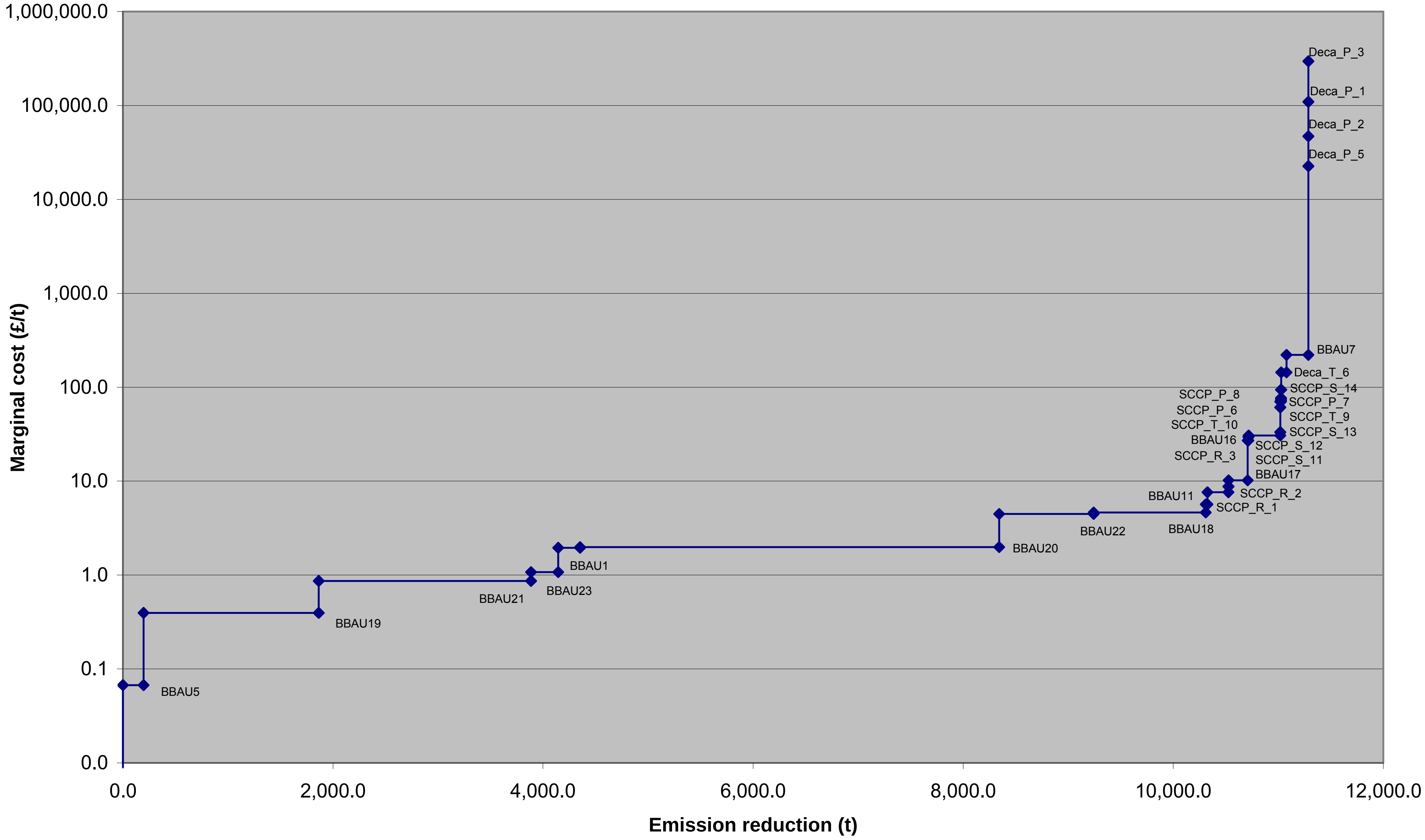
The cost curves were developed on the basis of emissions data for each environmental compartment. It would be a relatively straightforward exercise to develop separate cost curves for each environmental medium. This could be of value in the future if and when it becomes possible to provide further quantitative links between emissions reductions and environmental effects.

It is clear that there is significant variability amongst the three substances assessed as case studies for the current assessment in terms of data requirements and data availability. It is likely that, for many other chemicals, the level of information available will be even less than for these three substances. Data availability is a key issue in taking this approach forward to conduct more in-depth analyses on other substances.

Cost curves at the level of detail presented here can be produced relatively efficiently in terms of resource/time requirements, given the relatively high-level approach and existence of various data that has already been produced. Our project required approximately 50 man days (of staff including chemical risk specialists, economists and experts in cost curves for other regimes), including developing the method and applying it to the three case study substances, or about 12 days per case study. Cost curves for most other substances would almost certainly take longer than this because (a) the case study substances were selected on the basis that much information was already available; (b) only information already available in the public domain was used for the present study whereas collection of information from industry and others would probably be required for other substances, to achieve a robust analysis .

More sophisticated cost curves would require further data collection and analysis, such as detailed surveys of companies. Ultimately, the amount of resources required will depend on the level of detail needed for the intended use of the cost curves and the value of the information contained in the cost curves in decision-making.

Figure 8.1 Graphical illustration of combined cost curve for three substances (emissions removed and marginal cost)



8.2 Key limitations and uncertainties

Given that this is a pilot study, based on information already available in the literature, there are a number of limitations and uncertainties associated with the information used and presented *on the case study substances*.

For several of the cost estimates associated with substitution of chemicals, relatively little information is available on one-off costs (as opposed to price differentials for substitution). This means that the costs presented will tend to be underestimated. In addition, there is little information on inter-company differences in the levels of costs, such as where some companies are at different stages in examining potential for (and investing in) substitution than others, meaning differentials in companies' costs.

Experiences from other fields show that there are often difficulties in estimating costs of control measures prior to the implementation of legislation or other controls, with differences often evident in costs actually incurred compared to those that were predicted beforehand. It is often difficult to elicit good cost information from industry, given these uncertainties, as well as issues related to confidential business information.

The cost curves developed here are generally based on aggregate data on costs and emission reductions for a sector or specific application. In practice, emissions abatement potential and costs are specific to individual companies and products, meaning that there are significant uncertainties when estimating aggregate values alone. To establish cost curves that took into account individual companies' marginal costs and emissions abatement would be an immense undertaking and would be unlikely to be practicable in most chemical risk management contexts.

A number of possible substitutes are highlighted in the literature as being suitable and/or likely to be adopted in the event that a substance is no longer available. Relatively little information is available to determine the proportions in which different substitutes/alternatives would be adopted and it was necessary to make broad assumptions within this study. The actual substitutes or alternative approaches that would be adopted might therefore differ in practice.

Emissions and emission reductions are generally based on historical data rather than data for a projected year in the future. Relatively little information is available to estimate future changes in use/emissions in the absence of further regulatory changes. This adds further uncertainty, because changes since the data was collected in terms of uses, emissions and abatement are not fully taken into account.

In relation to measures to abate emissions to the environment, we mainly used general information on the types of abatement techniques that could be applied (for example, abatement techniques and associated cost/abatement efficiency data from IPPC BREF Notes). In practice, there will be significant differences between companies in terms of the abatement equipment that could be applied and its characteristics (size/cost/efficiency), as well as the extent to which abatement is already applied in practice. These were not taken into account in detail here, meaning that the measures presented are highly aggregated, average values. Costs and abatement for some uses and companies could therefore differ significantly from the average.

When estimating reductions in emissions, we also estimated reductions in releases from other lifecycle stages (such as reduced emissions from manufacture and from articles as a result of a ban on use in polymers) on a pro-rata basis according to the share of total use in that application. This does not take into account the fact that different uses have different relative emissions per unit of use. This simplification inevitably leads to additional uncertainty in estimates of overall emission reductions.

In most cases, we were not able to apply in detail every step of the proposed method. However, relatively simple work-arounds enabled us to develop cost curves (for example, by taking the most recent year's use and emission estimates as the baseline rather than those projected for a future year). The tables in the preceding sections outline the extent to which it was possible to apply the method for each substance.

Further examples of limitations and uncertainties are outlined in the preceding sections on each substance.

Given that the case study substances selected have more relevant data available than many other chemicals, these limitations and uncertainties are likely to be applicable for other substances; indeed, in many cases much less information will be available, making developing cost curves more difficult and resource intensive.

There are a number of limitations and uncertainties with the method in general. Cost curves provide relatively crude indications of the likely implications of an intervention to reduce emissions. They do not indicate the wider implications of measures, such as affordability or macroeconomic effects, which are typically included in impact assessments and other such analyses. Decision-making on new policies should take into account such factors.

The cost curves were developed at the level of entire uses of a substance, rather than distinguishing between companies within a particular sector or analysing the abatement options/costs for individual companies. They are thus at a relatively coarse level compared to cost curves developed at the level of individual business decisions. There may thus be significant variability for different companies and uses around the average values presented here.

The availability and robustness of information on business-as-usual emissions estimates and an understanding of what emissions abatement is already in place (a key step in developing cost curves) is also variable and in many cases based on 'realistic worst case' approaches used in risk assessments, which will tend to overestimate the level of emission reduction that could be achieved. It is clear that the reliability of the information included is dependent upon the quality of the baseline emissions and information used to derive and characterise that baseline.

Developing detailed, realistic cost curves could in some cases require confidential business information. The availability of such information – or lack thereof – could be a barrier to developing cost curves.

Some of these uncertainties and limitations could be reduced through further work, whilst others are inherent limitations of the approach.

8.3 Suggestions for further work

Having developed a draft method and applied this to a number of case studies, we now list suggestions for further work that could help to make the approach more operational.

A key question is, what specific uses could or should abatement cost curves have in informing regulatory decisions on chemicals?

Our suggestions for work to further develop the method are discussed below.

The data used in developing the cost curves thus far have been at a relatively coarse level, focused upon uses of a chemical in different sectors/applications, rather than individual companies. The method itself could be further extended to include individual abatement techniques (and substitution) at the level of individual companies or groups of companies, allowing for a more sophisticated picture of the potential costs of different measures. This would not require significant changes to the method but would be considerably more data intensive than the cost curves developed to date, including potentially extensive requirements on industry to provide information.

There is clearly a need for better and more consistent information on the costs of measures included in the cost curves. The data used for the illustrative case studies in this report have not necessarily been estimated on a consistent basis (coming from multiple data sources). It is therefore important that cost estimates are accurate and based on a consistent set of cost elements (system boundaries).

There were similar data gaps for all three substances necessitating the use of read across from different sectors. In particular, there was relatively little information on the applicability and costs of different technologies for abatement of emissions from formulation and use of the substances. It would be useful to have a reliable database of information on applicability, costs and emissions abatement potential of different techniques likely to be suited to chemicals. In general, for the substances considered there was relatively little differentiation between geographical areas, specific uses of chemicals and technical constraints; these aspects could be investigated further for individual chemicals. The extent to which additional information would be required depends on what level of aggregation is considered sufficient for decision-making and what is considered proportionate in terms of the time spent on such an analysis.

Given that baseline emissions are typically based on data from risk assessments, further work to understand the actual (rather than realistic worst case) emissions and the business-as-usual uptake of different abatement techniques would help to improve the accuracy and reliability of this approach. As a starting point, it would be worthwhile reviewing the level of information that becomes available through chemical safety assessments under REACH, once further registration dossiers are submitted.

A deliberate decision was made at the start of this work not to attempt to obtain additional primary data through consultation with industry, but instead to rely upon information already available in the literature in order to test the method. Consulting industry and other organisations on the implications of different measures could have generated more robust data and this should be borne in mind in further rolling out the method to other substances.

Each of the cost curves developed thus far is for a single substance, with multiple uses. They have not taken into account the implications of the potential abatement measures on emissions of other chemicals (or indeed other pollutants such as greenhouse gases or air pollutants). Links between the cost curves for different chemicals could highlight co-benefits of abatement measures for emissions of different pollutants as well as giving a more accurate overall picture of the implications of measures. Work such as Entec's 'multi-pollutant measures database' and IIASA's GAINS model are examples of where this has been done at different levels of sophistication.

The spreadsheet models used to develop the cost curves are not mainly automated and thus do not automatically calculate the effect of interactions of different measures on the same sector (for example, to avoid double-counting of abated emissions or costs). Further defining the rules for calculating the cost curves in an automated manner in such cases would add value to the method if it were to be rolled out more widely and could be more user-friendly for policy-makers.

Abatement cost curves provide only one part of the overall picture in terms of the implications of addressing environmental emissions of chemicals. They do not provide the policy-maker with information on what the actual implications would be of reducing emissions of any particular pollutant, nor do they provide information on the relative merits of reducing one unit of emissions of a substance compared to reducing the same unit emission of another. The ideal situation would be one where environmental and other benefits are fully understood and quantified. However, recognising that this is still a long way off, steps that could be taken to further differentiate between substances and better understand the implications of measures include the following.

A ranking or weighting approach could be developed for PBT and vPvB substances. Whilst an example is provided for combining costs curves for different substances, the benefits of controlling emissions (or use) of one chemical are unlikely to be similar to the benefits for other chemicals. Some chemicals are likely to be of greater concern than others and a weighting system taking into account pollutants' persistence, bioaccumulation potential and toxicity could help to distinguish better between substances. An approach similar to that for dioxins (Toxic Equivalents, TEQ, compared to that for 2,3,7,8-TCDD) is suggested by one member of the project board.

It would be helpful to further prioritise releases of substances to different environmental compartments in terms of their relative importance for environmental effects. At present, the method includes releases direct to the environment but it could be feasible to differentiate between these compartments in terms of the overall level of concern. For example, emissions to water might have a greater environmental impact than emissions to land and abatement of these emissions could thus have a greater environmental benefit. As a first step, releases to different environmental media could be given a relative ranking.

There remains a long way to go before we fully understand the benefits (and risks) of reducing emissions of chemicals to the environment. Further work such as those examples outlined above should take into account the likely future need to estimate: (a) spatial distribution of releases and emissions (reductions); (b) spatial distribution and longevity of concentrations in the environment; (c) effects on target organisms and ecosystems; (d) total harm associated with releases; (e) valuation where appropriate.

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10 Glossary

Average cost	This term is used to mean the average of the unit costs for a group of measures
BAU	Business as usual
BBAU	Beyond business as usual
BREF	Reference document on best available techniques under the IPPC Directive
Capex	Capital expenditure
CMR	Carcinogenic, mutagenic, reprotoxic (substance)
Cost curve	A set of measures or options to reduce releases of pollutants to the environment, defined according to the amount of release that each measure could remove, the associated cost of those measures and their cost-effectiveness in terms of cost per unit release removed
CSA	Chemical safety assessment (under REACH)
Deca-BDE	Decabromodiphenyl ether
DEHP	Di-2-ethylhexyl phthalate
DIDP	Di-isodecyl phthalate
DINP	Di-isononyl phthalate
ECHA	European Chemicals Agency
EEE	Electrical and electronic equipment
EPS	Expanded polystyrene
GAC	Granular activated carbon
HBCDD	Hexabromocyclododecane
HIPS	High impact polystyrene
IPPC	Integrated Pollution Prevention and Control Directive (2008/1/EC)
LCCPs	Long-chain chlorinated paraffins
Marginal cost	In this report, the unit costs of a single abatement measure are described as a ‘marginal cost’, being marginal to measures already in place to reduce the emissions (or use) of a particular chemical, for example, on grounds of cost
MCCPs	Medium-chain chlorinated paraffins
OEL	Occupational exposure limit
Opex	Operating expenditure
PBT	Persistent, bioaccumulative and toxic substance (Annex XIII of REACH)
POPs	Persistent organic pollutant

R&D	Research and development
REACH	Regulation (EC) No 1907/2006 of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)
Risk management measure	Concrete measures and operational conditions taken by industry to control the exposure to a substance
Risk management option	Any possible changes to legislation or other requirements on industry (e.g. in permits) to control identified risks. They may also cover the use of economic instruments and industry’s voluntary commitments.
RoHS	Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment
SCCPs	Short-chain chlorinated paraffins
SMEs	Small and medium-sized enterprises
STW	Sewage treatment works
SVHC	Substance of Very High Concern (Title VII of REACH)
tpa	Tonnes per annum
vPvB	Very persistent, very bioaccumulative substance (Annex XIII of REACH)
WEEE	Waste electronic and electrical equipment
WFD	Water Framework Directive (2000/60/EC)
WWTP	Waste water treatment plant

Appendix A – Outputs of literature review

The following tables provide the outputs of the review of some existing cost curve approaches.

Development of a Multi-Pollutant abatement Measures Database (MPMD) and scenario analysis [Contractor: Entec; Client: Defra, ongoing]

Purpose/Policy Objectives:

The aim of this work is to support Defra during its negotiations on proposals for a revised Gothenburg Protocol and National Emission Ceilings Directive (NECD, 2001/81/EC). The NECD currently sets national level caps on emissions of NO_x, SO_2, VOCs and ammonia to be met by 2010 but when revised will include new ceilings for 2020 (and include a ceiling for particulate matter). This work will provide Defra with a tool for assessing the possible costs and benefits of meeting future targets for all of these pollutants by developing cost curves for a number of scenarios e.g. least cost scenario, ‘expected future policies’ scenario and others to be discussed with Defra.

Scope:	
Geographical	UK only
Sectoral coverage	MPMD currently includes over 140 abatement measures for 23 priority (highest emitting) sectors
Pollutants	Measures developed primarily for NO_x, SO_2, PM_{10}, $PM_{2.5}$, VOCs. Multi-pollutant impacts on range of other pollutants considered including CO_2, CO, NH_3, N_2O, CH_4.
Media	Emissions to air
Reference year for analysis	2010, 2015 and 2020

Overview of approach:

How has it been developed?

The following steps have been taken to develop the MPMD:

- **Defining the baseline:** a key task for the MPMD work has been the review and scrutiny of the existing BAU emission projections developed for the UK. As these are to be used as the starting point for additional abatement and scenario analysis it is critical that the underlying assumptions for each sector/pollutant of interest are clearly understood and only beyond-BAU abatement measures are considered, hence avoiding “double-counting” (overestimating possible emission reductions).
- **Identification of priority sectors/pollutants:** a screening exercise has been undertaken to identify the priority sector/pollutant combinations to target in order to focus on the most significant emission sources. It was agreed with Defra that all sectors contributing more than three per cent to total emissions of a particular pollutant and most sectors contributing more than one per cent would be included in the scope of work.
- **Development of abatement measures and costs:** a series of abatement measures have been developed for each of the selected priority sector/pollutant combinations. These have been developed based on existing Entec work in this area, a review of literature (e.g. BREF documents) and extensive consultation with stakeholders (see data sources for details). To date (March 2010), the MPMD includes over 140 abatement measures for 23 priority sectors. For each measure the following information has been gathered and/or calculated:
    - BAU uptake: What uptake has already taken place and/or is anticipated in the future?
    - Applicability (sectors, fuels, plant/vehicle types etc.): What is the maximum technically feasible uptake?
    - Costs: These covered one-off capital costs, operating costs (including maintenance) and administrative costs e.g. additional training. Costs are calculated into total annualised costs.
    - Operating life of measure.
    - Multi-pollutant impacts in 2015 and 2020, that is, impacts on emissions of relevant pollutants as well as greenhouse gases.

- **Development of cost curves/scenario analysis**: this phase of the work is currently ongoing and to date (March 2010) Entec has developed a series of cost curves for each pollutant of interest based solely on the most cost-effective measures in the database (least cost compliance). Interactions between measures (e.g. mutually exclusive) are taken into account to avoid overestimation of emission reductions. Further scenarios are currently being discussed with Defra.

Data sources used

- Baseline emissions: The National Atmospheric Emissions Inventory (NAEI) for the UK has been used[21].
- Projected emissions (if applicable): NAEI emission projections for 2010, 2015 and 2020.
- Existing uptake of abatement measures (sector/installation level): NAEI projections and the underlying inventory are based primarily on regulatory limits rather than on the technologies expected to be implemented. This has been addressed through the use of expert judgement and consultation with the NAEI team and industry groups.
- Possible future abatement measures (applicability, efficiency, costs etc.): a review of the cost curves produced by IIASA's GAINS model for the UK, direct consultation with industry, trade associations, abatement equipment suppliers, regulatory authorities and other experts and a literature review was undertaken.

Types of abatement measures

Range of measures including end-of-pipe abatement, efficiency improvements, behavioural change, fuel switching, technology switching etc.

Links to benefits?

Associated health and environmental benefits have been estimated based on damage cost functions developed by the Interdepartmental Group on Costs and Benefits (IGCB). Damage cost functions are applied to the estimated emission reductions, that is monetary value per tonne of pollutant reduced. The calculation of abatement costs and associated benefits achieved can be used to take an alternative approach to prioritising measures and developing cost curves e.g. based on cost-benefit ratios.

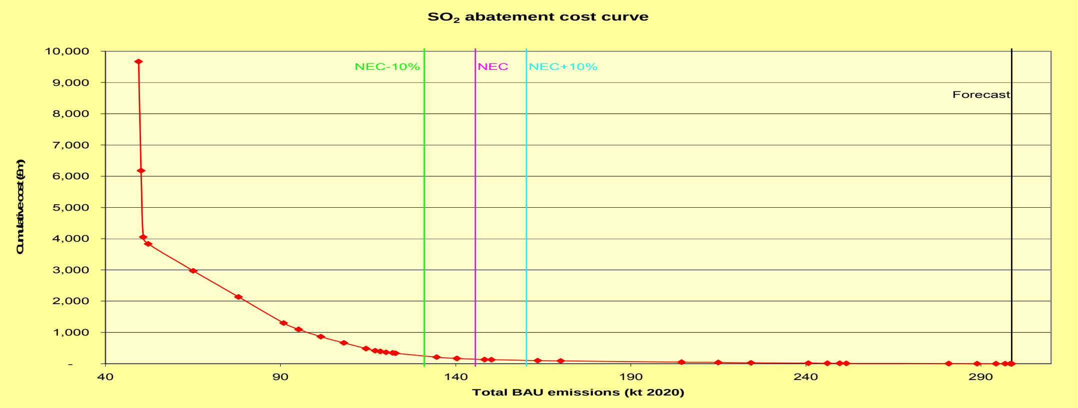
Outputs

MPMD currently includes over 140 abatement measures for 23 priority (highest emitting) sectors. These have been used to develop cost curves for each pollutant of interest based on a least cost approach (an example for SO_2 is provided below). For each measure in the MPMD the following has been estimated:

- Applicability (sector/subsector, fuels, plant/vehicle types, retrofit/new).
- BAU uptake (under current policy).
- Maximum technically feasible uptake, beyond BAU uptake.
- One-off capital costs, operating costs including maintenance, operating life and annualised cost.
- Multi-pollutant impacts.
- Cost-effectiveness, £/tonne abated.
- Indicative benefits based on IGCB damage cost functions).

A final report for the database (excluding the scenario analysis) is available on Defra's website:

www.defra.gov.uk/environment/quality/air/airquality/publications/airqual-climatechange/documents/measures-database.pdf



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[21] http://www.naei.org.uk/?lang=_e

Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model and cost curves [Contractor: IIASA; Client: European Commission, ongoing]

Purpose/Policy Objectives:

The GAINS model has been developed by the International Institute for Applied Systems Analysis (IIASA) to support policy decision making at a European level. The model has been used to develop a number of air quality and climate change scenarios that the European Commission has been using for policy development and the consideration of future policy packages, such as for setting the 2020 National Emission Ceilings (NECs) at an EU and MS level. The model has been developed as part of the Clean Air for Europe (CAFE) programme. The GAINS model is also available online for interested parties[22].

Scope:

Geographical	The GAINS model for Europe covers 43 countries in Europe including the European part of Russia. IIASA has also developed versions of the GAINS model for Annex I countries to the UNFCCC, South Asia, China, Russia and the "Rest of the World".
Sectoral coverage	The GAINS model has data disaggregated primarily by model specific categories. In addition, data can be displayed for the following international emission reporting standards: CORINAIR SNAP1, UNECE NFR1 and NFR2. The model aims to cover all emission sources to air (air pollutants and greenhouse gases).
Pollutants	Emissions and abatement measures developed for air pollutants NO_x, SO_2, $PM_{10 \& 2.5}$, NH_3 and VOCs and for greenhouse gases CO_2, CH_4, N_2O, SF_6, HFCs and PFCs (as included by the Kyoto Protocol). The model contains approximately 1,500 end-of-pipe measures to reduce emissions of air pollutants (SO_2, NO_x, NH_3, VOC and PM) as well as a range of options to reduce greenhouse gas emissions. Impacts of abatement measures on more than one pollutant are considered in the model.
Media	Emissions to air
Reference year for analysis	2000 (base year), 2005, 2010, 2015, 2020, 2025 and 2030

Overview of approach:

How has it been developed?

Previous to the GAINS model, the IIASA team had developed the RAINS (Regional Air Pollution Information and Simulation) model to assess and analyse the emissions and costs of controlling emissions of traditional air pollutants such as SO_2, NO_x, VOCs, NH_3 and PM. The RAINS model was then extended to explore synergies and trade-offs between the control of local and regional air pollution and the mitigation of greenhouse gas emissions, hence the name GAINS. The previous version, the RAINS, analysed and calculated cost curves on a "single pollutant basis". However this approach has its drawbacks, particularly if one abatement measure has an impact on more than one pollutant (plus interactions with greenhouse gases were not explored).

The GAINS model is "technology based", applying different abatement measures to unabated emissions to develop a series of baseline scenarios. The model then uses an 'optimisation approach' whereby the most cost-effective combination of control measures are selected (for any pollutant) that can meet predefined environmental targets such as those developed under the Thematic Strategy for Air Pollution. The key attributes of the GAINS model include:

- Activity data: this presents data on underlying energy-use, industrial processes, agriculture and transport, both for past and future years broken down by country or group of countries (for example, EU27). The baseline activity data are taken from the PRIMES energy model and/or individual MS.
- Emissions: this shows emissions for a selected scenario (combination of activity pathway and emission control strategy).
- Costs: emission control costs computed by the GAINS model for a selected emission scenario are shown and details are provided on the cost-relevant input data used for the calculations.
- Impacts**:** provides information on ecosystem sensitivities and human health impacts of air pollution. The results can be displayed in graphical (maps) and numerical form (tables with country-specific data).

In order to develop different emission baselines and scenarios, the GAINS model incorporates all current and future legislative requirements e.g. Emissions Limit Values for large combustion plants under the Large Combustion Plant Directive, of current and future legislation.

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[22] http://gains.iiasa.ac.at/index.php/gains-europe

	The data in the model has been gathered over a number of years through ongoing consultation with Member States, industry, technology suppliers, expert groups as well as review of literature.
Data sources used	• Baseline emissions: the model includes baselines/scenarios based on national activity data (provided by Member States) as well as modelled activity data for each Member State from the PRIMES model (developed by the National Technical University of Athens. • Projected emissions (if applicable): these are developed based on the combination of activity pathway and emission control strategy selected using either national level projections or those from the PRIMES model. • Existing uptake of abatement measures (sector/installation level): based on review of current and future legislative requirements, stakeholder consultation, BREFs, Expert Group on Techno-Economic Issues (EGTEI) working group and so on. • Possible future abatement measures (applicability, efficiency, costs etc.): see above.
Types of abatement measures	Wide range of measures: fuel switching, end-of-pipe abatement, activity change, behavioural change, technology switching.
Links to benefits?	Yes – model provides health and ecosystem impacts of particulate pollution, acidification, eutrophication and tropospheric ozone (based on existing modelling undertaken by the European Monitoring and Evaluation Programme (EMEP)).
Outputs	The GAINS model is used to develop and assess a range of air quality and greenhouse gas emission scenarios in order to inform policy development at an EU level. For each scenario it provides an estimate of emissions, costs and impacts (health and environmental) at an EU and Member State level. For each abatement measure the following elements are included: • Applicability (sector/subsector, fuels, plant/vehicle types, retrofit/new). • Uptake under each of the scenarios investigated. • Maximum technically feasible uptake. • One-off capital costs, operating costs including maintenance, operating life and annualised cost. • Multi-pollutant impacts. • Cost-effectiveness. Cost curves can also be downloaded for each Member State. These are produced by the model and rank measures in order of cost-effectiveness. For further details on the GAINS model see the website http://gains.iiasa.ac.at/gains/EUR/index.login?logout=1

Assessment of the possible development of an EU-wide NO_x and SO_2 emission trading scheme for IPPC installations [Contractor: Entec; Client: European Commission, ongoing]

Purpose/Policy Objectives:

The key objective of this study is to assess the environmental, economic and social impacts of various designs of an Emission Trading Scheme (ETS) for SO_2 and NO_x under certain EU-wide rules for IPPC installations (as an alternative to individual Best Available Technique (BAT)-based permitting of IPPCD and IED Proposal for those pollutants). The key overriding criteria in this study for the development of a market-based instrument (MBI) such as an ETS for IPPC installations included:

- The health and environmental impacts should not to exceed those under current legislation and the Industrial Emissions Directive (IED) Proposal (reference scenario).
- Constraints due to potential NECD 2020 ceilings to be assessed, as well as benefits of flexible ceilings.

Overall, the study is to provide enough insight to determine whether a trading mechanism for SO_2 and NO_x for IPPC installations in the EU would be an appropriate market-based instrument. If found so, it is to be made clear under which specific rules the instrument may be applied successfully, safeguarding at least the environmental objectives under the current legal framework and ensuring its practicability and enforceability.

Scope:

Geographical	EU27 Member States
Sectoral coverage	IPPC sectors included in the installation database: combustion plants over 50 MW, oil refineries, coke plants, integrated steelworks (including sintering plants), cement plants, glass manufacturing and pulp & paper installations. The selected sectors accounted for over 90 per cent of SO_2 and NO_x emissions in 2004 (based on those installations in the European Pollutant Emissions Register (EPER) database).
Pollutants	Primarily SO_2 and NO_x although impacts on PM emissions have also been considered
Media	Emissions to air
Reference year for analysis	ETS would start from 2016 – main results presented for 2020

Overview of approach:

How has it been developed?

The following steps have been taken in the MBI study:

- **Development of an installation database** to provide a detailed, installation-level, bottom-up business-as-usual scenario and to enable the development of a reference scenario for comparison. The database contains over 5,000 EU installations in the selected sectors. To prioritise the sectors the following criteria were applied:

  a) Average emissions per installation for a sector which are above a specified percentage of the average across all IPPC sectors. A threshold equivalent to 50 per cent was applied.

  b) Total emissions for a sector which are above a specified percentage of emissions from all IPPC sectors. A threshold equivalent to one per cent was applied.

  The following data were gathered/calculated at an installation level:

  - Source location and stack characteristics (stack height, exit velocity exit etc).
  - Capacity, throughput and fuel type and consumption.
  - Emissions and emission concentrations.
  - BAU abatement, beyond BAU abatement potential, lifetime, costs (annualised) and efficiencies of abatement measures.

- **Options for emission trading scenarios:** a 'shortlist' of design options was drawn that would assess the environmental and economic impacts for ET scenarios and the desirability of a potential NO_x and SO_2 ETS for IPPC installations. The shortlist took into account experiences of similar trading schemes, the experience of the project team, discussions with the Commission, and a stakeholder workshop in April 2009.

- **Trading Simulation Model (TSM):** The TSM was developed to model the shortlist of emissions trading scenarios and estimate their impacts on emissions and costs at an installation, sector and MS level. At the core of the TSM lies an optimisation module which aims to minimise the costs of abatement across a group of installations in a pre-defined trading zone and meet a number of constraints such as the emissions cap or the NECD (2010 and potential 2020) constraints. Essentially the modelling ranks suitable abatement measures for each installation in order of cost-effectiveness. The TSM results include emissions and costs for each trading scenario as well as the underlying abatement solutions.

	• **EMEP modelling:** This modelling had two purposes in this study: firstly source-receptor modelling (at 50x50 km resolution) to indicate the sensitivity of a marginal change in emissions of SO_2 or NO_x on health and environmental impacts; and secondly, modelling (at 10x10 km resolution) of air quality impacts and associated health and environmental impacts.
Data sources used	• Baseline emissions: EPER 2004 (for all EU27 MS), LCPD 2006 emission inventories, E-PRTR 2007 (for some MS), stakeholder consultation with EU trade associations, MS competent authorities and BREF specialists. • Projected emissions (if applicable): Stakeholder consultation with EU trade associations, MS competent authorities and BREF specialists. In addition PRIMES gross value added projections have been used to project activity data for each sector. • Existing uptake of abatement measures (sector/installation level): Entec previous studies related to LCPD and IPPC; Stakeholder consultation with EU trade associations, MS competent authorities and BREF specialists. • Possible future abatement measures (applicability, efficiency, costs etc.): Stakeholder consultation with EU trade associations, MS competent authorities and BREF specialists; GAINS model assumptions.
Types of abatement measures	End-of-pipe, closure of plants and rebuild, fuel switching, technology switching, primary measures.
Links to benefits?	Yes – the TSM outputs have been used as an input to the EMEP model to estimate air quality and associated environmental and health impacts across the EU. Some of these impacts have then been monetised using appropriate health values.
Outputs	The study is investigating whether a trading scheme for SO_2 and NO_x emissions for IPPC installations would be an appropriate regulatory mechanism. A number of emission trading scenarios have been developed and their key impacts in terms of costs and monetised health and environmental benefits relative to the reference and BAU scenarios considered. The modelling year for the study was 2020 and for every ET scenario the key outputs are the cost-effectiveness, costs, benefits and emissions. More specifically for the installation database, the following key information has been gathered and developed at an installation level: • Source location and stack characteristics. • Current and projected emissions for 2020 based on sectoral activity changes and BAU uptake of measures, and emission concentrations (for the majority of installations). • A list of BAU and beyond BAU abatement measures: details include lifetime, costs (annualised) and efficiencies. • Cost-effective measures applicable at an installation level (ranked in order of cost-effectiveness). A draft final report for the MBI study is available on the CIRCA website: http://circa.europa.eu/Public/irc/env/ippc_rev/library?l=/emissions_trading/strakeholder_february&vm=detailed&sb=Title

Costs and Benefits of Abatement Options for Greenhouse Gas Emissions from Ships Arriving at and Departing from Ports in the UK [Contractor: Entec; Client: DfT, 2009-2010]

Purpose/Policy Objectives:

Purpose

This study develops new information on technical and operational measures that could reduce emissions of CO_2 and other greenhouse gases (GHGs) beyond business as usual levels for the UK and presents this information in the form of Marginal Abatement Cost Curves (MACC) for 2020 and 2050. It does not quantify the cost of removing the potential barriers to implementation – the MACCs represent maximum technical potential rather than what is realistically expected to occur at a certain carbon price.

Policy Context

The UK Climate Change Act (2008) includes domestic shipping in the carbon budgets and the Committee on Climate Change is interested to know the present and future technological options to reduce emissions. In addition, the Secretary of State is expected to make provisions through regulations on international aviation and shipping by the end of 2012 or report to Parliament explaining why such regulations have not been made.

Scope:

Geographical	UK only
Sectoral coverage	Shipping. Separates shipping sector into 70 vessel categories according to size and type. Nineteen groups of abatement options were included, totalling 34 abatement options.
Pollutants	Abatement options focussed primarily on CO_2. Other greenhouse gas impacts considered, including methane; options to reduce refrigerant gases assessed quantitatively. Cross-media impacts on non-GHG pollutants considered qualitatively.
Media	Emissions to air
Reference year for analysis	2020 and 2050

Overview of approach:

How has it been developed?	• Develops baseline GHG projections for UK shipping on basis of activity rate projections and takes into account the impact of forthcoming air quality legislation on projected fuel costs. • Includes an updated analysis of the fuel type mix and robust marine fuel prices on the basis of detailed historic econometric analysis. • Updates existing cost estimates for technology and operational measures to reduce GHGs and develops cost and effectiveness data for new technology and operational measures. • Provides a detailed analysis at the level of 70 different vessel type/size categories, taking into account the applicability of measures and their likely sequence for all the different vessel categories, adding insights to which vessel types should be targeted as a priority and overall enhanced precision of the cost and abatement volume estimates. The approach limits the potential for double counting and negative interaction of measures therefore limits uncertainty. • Highlights the most promising measures for the vessels travelling to and from the UK and produces estimates of the technical potential for emission reduction volumes for UK domestic and international shipping with added qualitative descriptions of barriers to implementation that may affect this potential.

Data sources used	Baseline emissions • Lloyds Marine Intelligence Unit databases provided fleet breakdown and distances travelled. Using emission factors Entec derived emissions. Projected emissions • International Maritime Organization (IMO) assumptions used to project business-as-usual uptake of speed reduction measure. • Activity trends provided for by MDS-Transmodal (a consultant for the DfT). • Fuel type trends, taking into account MARPOL Annex VI amendments and its impacts on uptake of sea water scrubbing, biofuels and liquid natural gas as alternatives to lower sulfur fuel oil, based on IMO and Marintek assumptions. Existing uptake of abatement measures (sector/installation level) and possible future abatement measures (applicability, efficiency, costs etc.): • Literature review. • Industry workshop (participants: shipping companies, Maritime Coastguard Agency, the Department for Transport (DfT) and NGO representatives). • Interviews with technology manufacturers and energy sector experts.
Types of abatement measures	Many different types of abatement options were included: • Activity change (e.g. efficiencies of scale). • Behavioural change (e.g. speed reduction, weather routing). • Fuel switching (e.g. wind, solar, liquefied biogas, biofuels, fuel cells). • Technology switching (e.g. propeller measures, main engine retrofits, hull coating and cleaning).
Links to benefits?	Not assessed
Outputs	The main study outputs are marginal abatement cost curves, for each of domestic, international and total shipping, in each of the 2020 and 2050 focus years. These MACCs plot abatement (t, x-axis) against cost effectives (£/t abated, y-axis), with each measure represented by a bar of area equal to total cost of the measure; the measures are ordered by cost-effectiveness. Other key data outputs include: • Baseline and projected emissions for domestic and international shipping (2007, 2020 and 2050). • For each abatement option group, estimates of: o Applicability (vessel type/size, retrofit/new, etc). o BAU uptake (under current policy). o Maximum technically feasible uptake. o One-off capital costs, operating costs including maintenance, operating life and annualised cost. o Effectiveness in CO_2 abatement. A final report for the client is currently in the process of being agreed.

Projections of emissions and development of cost curves for non-CO_2 greenhouse gases [Contractor: Entec; Client: Defra, 2003-2006]

Purpose/Policy Objectives:

To develop projections of emissions of the five greenhouse gases other than CO_2 that are covered under the Kyoto Protocol and to develop marginal abatement cost curves for potential abatement in the future.

Scope:

Geographical	UK only, with emissions projections developed for the UK constituent countries
Sectoral coverage	Sectors with major share of total emissions and, following screening, significant potential for emission reductions
Pollutants	CH_4, N_2O, HFCs, PFCs, SF_6
Media	Emissions to air
Reference year for analysis	2005, 2010 and 2020

Overview of approach:

How has it been developed?

The following steps were taken in developing the cost curves:

- Defining and characterising baseline emissions (based on national GHG emissions inventory).
- Projecting future changes in emissions up to 2020 and beyond based on changes in underlying activity rates (fuel consumption, population, GDP, emissions abatement, plant closures, etc.).
- Identifying specific measures that could be applied to each of the main emissions sources.
- Estimating emission reduction that could be achieved for defined sector level emissions under each measure based on percentage reduction efficiency and percentage applicability to those sectors.
- Estimation of capex and annualised capital cost (based on 3.5 per cent discount rate and specified economic life of measure), annual operating costs and thus total annualised costs.
- Estimation of abatement potential in each reference year (see above) as well as abatement cost for each measure.
- Ranking of abatement measures in terms of cost-effectiveness.
- Development of cost curves, including graphical representation, for each pollutant individually and for all five GHGs combined (based on global warming potential to give emission abatement in consistent units).

Data sources used

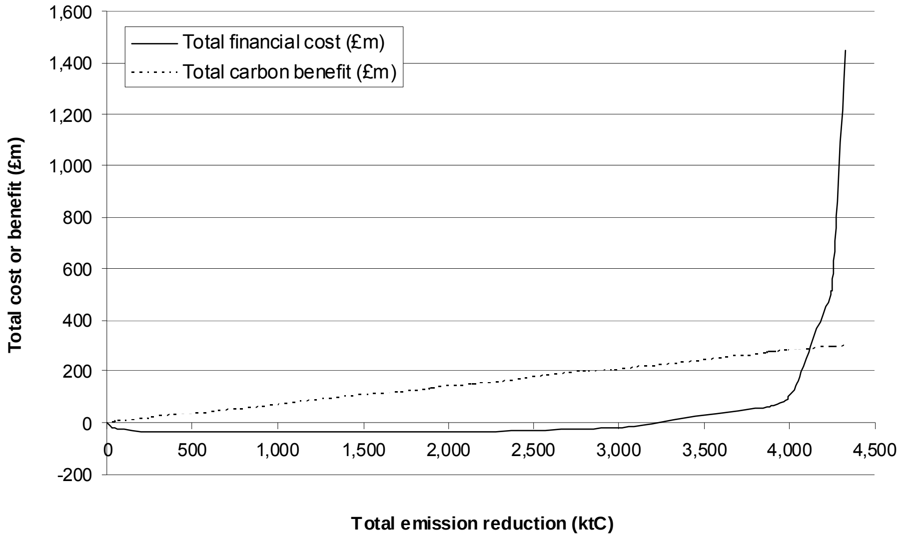
- Baseline and projected future emissions based on ‘with measures’ emissions projections for all major sectors.
- Consultation with stakeholders and review of technical literature and in-house data available to Entec to estimate future uptake of existing measures and potential future measures that could be implemented.
- Other Defra-funded work used/incorporated on potential abatement for waste, agriculture and fluorinated gases.

Types of abatement measures

A range of measures were considered, including technical abatement measures, those applying to agriculture (e.g. changes in feedstock), substance recovery.

Links to benefits?

Emissions abatement was linked to an assumed cost of carbon (applicable at the time) of £70/tC. This allowed the point where overall net benefits would be achieved to be identified, as shown below.



Outputs

The main data outputs from the study were as follows:

- Applicability to individual sectors and subsectors.
- Maximum technically feasible uptake.
- One-off capital costs, operating costs including maintenance, operating life and annualised cost.
- Cost-effectiveness.
- Emissions abated and associated costs of measures for individual pollutants (CH_4, N_2O, HFCs, PFCs, SF_6) and combined total based on global warming potential.
- Indicative benefits based on cost of carbon approach.

Appendix B – Data for cost curve for SCCPs

Note on prices

In the main report, information on costs of abatement measures is presented in 2010 Sterling values. This appendix may include cost data presented in other currencies and/or in prices from different years, particularly where the original data sources used different currencies. The conversions are included in the accompanying spreadsheets.

Characterisation of possible abatement measures

Releases to surface water and waste water

Environmental releases arise from manufacture of short-chain chlorinated paraffins (SCCPs) and from the use of articles, as shown in Table 5.1 in the main part of this report.

It is, in principle, possible to further reduce emissions of SCCPs from manufacture through the removal of the substance from the waste stream. Controls on emissions from articles would require restrictions on the use in these articles (although this would not affect emissions from articles that are already in use).

Previous studies concerned with the WFD reviewed for this project (such as the partial cost-effectiveness analysis for Defra and studies undertaken by UKWIR) did not consider costs of abatement measures for SCCPs because the restrictions in place were considered to be sufficient to meet EQS values. For these UK studies, no inputs were expected from domestic, runoff or town centre sources. Only fugitive industrial inputs were thought possible (although none were measured in screening studies). Measured effluent data was less than the EQS value so, given the source controls in place, abatement measures for SCCPs were not considered further[23].

Given that SCCPs are a priority hazardous substance under the WFD, there is a requirement to cease or phase out discharges, emissions and losses, although the studies referred to above assumed that meeting the EQS would be sufficient to comply with the WFD. This cessation of emissions is essentially the objective of REACH, since for PBT substances no exposure is acceptable and a predicted no effect concentration (PNEC) cannot be derived. In terms of assessing the measures that could be put in place, the imposition of measures to remove residual SCCPs in the aqueous waste stream in order to remove the input from fugitive emissions could be used.

Estimates of the efficiency of removal of SCCPs in waste water treatment works applying tertiary treatment (activated sludge) are up to 93 per cent removal[24] (because

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[23] *Dangerous substances and priority hazardous substances/priority substances under the Water Framework Directive, initial report: A comparison between options and costs for source control versus end-of-pipe treatment.* UK Water Industry Research, 2007.

[24] *Priority hazardous substances, trace organics and diffuse pollution (Water Framework Directive) treatment options and potential costs*. UK Water Industry Research, 2004.

of the low solubility in water (K_{ow} = 6.2), partition in a sewage treatment works is predominantly to sludge). Therefore, to capture the remaining seven per cent it could be possible to apply additional technical abatement to particular sewage works.

The costs of measures such as granular activated carbon (GAC) have been estimated for other substances for which a need to apply abatement has been assumed (such as DEHP). Such measures would also reduce emissions of SCCPs and the associated costs could potentially be applied to application of this technique to reduce emissions of SCCPs. However, because GAC can be applied to a number of substances, there would be a need to ensure the costs attributable to SCCPs alone are estimated or the fact that such techniques would affect other substances at least acknowledged. The costs of abatement using GAC have been estimated based on data from the IPPC BREF Notes, in particular the BREF on common waste water treatment for the chemicals industry (European Commission, 2009).

The remaining emissions from industrial sources are thought to be largely from fugitive sources. It may be possible to further abate such fugitive releases, although no suitable data has thus far been identified.

Alternatives

The measure(s) likely to be most effective in removing the majority of emissions of SCCPs to the environment relate to removal of the use of the substance through the use of alternatives. This is because releases from articles containing SCCPs constitute the single largest source of release to the environment and because there are unlikely to be feasible technical measures that would allow such releases to be abated.

Information on alternatives is presented in the table below.

Table B1.1 Summary of alternatives to SCCPs

Use	Alternative	Availability and cost	Comments
Rubber	Medium and long-chain chlorinated paraffins; aryl phosphates	All commercially available. MCCPs - similar cost. LCCPs - higher cost - higher use rate and additional one-off costs. Aryl phosphates - significantly higher substance costs; additional one-off costs.	No non-substance based alternatives identified
Textiles	MCCPs LCCPs Decabromodiphenyl ether Hexachlorocyclododecane Ethane, 1,2-bis(pentabromo-phenyl)	All commercially available. MCCPs - similar cost. LCCP - higher cost - higher use rate and additional one-off costs. Brominated compounds - significantly higher substance cost than; SCCPs; additional one-off costs. Also requires diantimony trioxide as synergist	
Sealants and	Flame retardant function: MCCPs,	All commercially available. MCCPs - similar cost	

Use	Alternative	Availability and cost	Comments
adhesives	LCCPs Plasticising function: Phthalate plasticisers	LCCP - higher cost - higher use rate and additional one-off costs.	
Paints and coatings	MCCPs LCCPs	All commercially available. MCCPs - similar cost LCCP - higher cost - higher use rate and additional one-off costs.	Other alternatives could include phthalate esters, polyacrylate esters, diisobutyrate as well as phosphate- and boron-containing compounds (the latter where flame retardancy of the final paint is important).

[1] Data from ECHA (2009c).

Based on the analysis in the ECHA report on uses and releases, some quantitative information is available that could be used in the development of cost curves, as illustrated in the table below. This includes information on the increase in purchase price/cost of using alternatives in the various applications and does not include the (one-off) costs of product reformulation. The cost estimates are therefore likely to be an underestimate of the total costs. Furthermore, the cost estimates are subject to significant uncertainty, as outlined in the supporting report.

Table B1.2 Possible increase in costs for use of alternatives to SCCPs[1]

Use	Possible alternative	Increase in purchase price (€/t of SCCP replaced)
Rubber	MCCPs	€80/t
	LCCPs	€200/t
	Cresyldiphenyl phosphate (and other phosphates)	€1,000/t
Textiles	Deca-BDE	€110/t
	HBCDD	Slightly higher than deca-BDE
	Ethane, 1,2-bis (pentabromophenyl)	Slightly higher than deca-BDE
Sealants, adhesives, paints and coatings	MCCPs	€80/t (as for rubber)
	LCCPs	€200/t (as for rubber)
	Phthalates	€300/t

[1] Costs are subject to significant uncertainty and do not include reformulation costs, which may be significant.

Other issues

If (for the purposes of illustrating the potential use of cost curves) we assumed that the use of leather liquors and metalworking fluids had not been restricted, we could assess what could be achieved by imposing abatement measures to take out the residual concentration in waste water (for example by consulting BREFs as well as some of the analysis done for the Water Framework Directive – although not necessarily for SCCPs *per se*). In addition, the assessment could consider the costs of alternatives for remaining uses and for uses not currently subject to restriction.

In practice, such an approach was not adopted in developing the cost curves for this substance and this approach (using historical data where some uses have been restricted) was instead applied for deca-BDE.

Data for incorporation into cost curves

The table below outlines the assumptions and data used in developing specific measures for the cost curve for SCCPs.

Table B1.3 Summary of measures for inclusion in cost curve

Measure	Details of key elements of measure
Rubber – use of alternatives	*One-off costs*: Total R&D costs for replacement of all uses based on RPA (2010) report which gives €38,000 to €150,000 for conveyor belt manufacture and €0 to €563,000 for other uses. Mid-point values give €375,000 in total. Assuming amortisation period of five years gives equivalent annual cost of €69,200, which is assumed to be distributed proportionately amongst companies choosing different substitutes (see below). Total costs are for use as a whole in this application rather than per company.
	Recurring annual costs: Replacement with MCCPs costs €80/t; with LCCPs €200/t; with organophosphates €1,000/t of SCCP replaced. All based on ECHA (2009c).
	Emissions reduced: All emissions from rubber formulation and processing are removed with 100 per cent substitution (1.20 t). Additionally, assumed proportional reduction according to share of use in this application for emissions from manufacture (giving 0.02 t) and articles (18.05 t). Total emission reduction = 19.27 t.
	Applicability of measures: No information on which alternatives will be chosen by firms concerned. Assumed 80% of use is replaced with MCCPs, 10% LCCPs and 10% organophosphates (own assumption to illustrate variety of options likely to be adopted and reflecting that different applications will require different substitutes).
	Specific measures taken forward: SCCP_R_1: Replacement with MCCPs SCCP_R_2: Replacement with LCCPs SCCP_R_3: Replacement with organophosphates
	Interactions with other measures: Could not be applied simultaneously with measures to reduce emissions from rubber formulation/processing.
	Main uncertainties and limitations: - Data on costs of alternatives are relatively old and subject to uncertainty. - Data on one-off R&D costs do not take into account range of values. - Emission reductions are based on historical use and emissions (more recent data suggest current uses are lower but comparable emission data were not available). - Reduction in emissions from articles is only based on share of use, not relative emissions (per unit of use) from specific articles concerned. Also assumes steady state is reached (emissions from articles would continue to occur for some years after use ceases).

Measure	**Details of key elements of measure**
Rubber – additional waste water treatment	*One-off costs*: Assumed €100,000 capital cost for granular activated carbon (GAC), based on range of €50,000 to €1,000,000 quoted in European Commission (2009) (low end of range taken as sites likely to have relatively small flows). An amortisation period of 10 years was assumed. Assumed to be applied by 13 companies, based on RPA (2010).
	Recurring annual costs: Assumed to be €10,000 per year, or 10 per cent of capital cost.
	Emissions reduced: Assumed to apply to all emissions to waste water from rubber formulation and processing (0.6t). Emission reduction efficiency assumed to be 90 per cent, giving 0.54t emission reduction.
	Applicability of measures: It is unknown to what extent such water treatment techniques are already operational or whether there are technical constraints that would prevent GAC being applied. We assumed that it could be applied in all cases.
	Specific measures taken forward: SCCP_R_4: Additional waste water treatment (GAC).
	Interactions with other measures: Could not be applied simultaneously with measures to replace SCCPs altogether. Could be applied with measures to reduce emissions to air.
	Main uncertainties and limitations: - Extent to which GAC could be applied in practice at the installations concerned is unknown and assumptions were made for the purposes of this pilot study to illustrate the value of including a range of measures in the cost curve. - Size and associated cost of GAC required is unknown. We assumed a relatively small unit. - Emission reduction efficiency will depend upon waste water concentrations and other factors. The value assumed here is subject to uncertainty.
Rubber – abatement of emissions to air	One-off costs: €150,000 for thermal oxidiser based on Entec (2008). An amortisation period of 10 years was assumed. Assumed to be applied by 13 companies, based on RPA (2010).
	Recurring annual costs: Assumed to be €15,000 per year.
	Emissions reduced: Assumed to apply to all emissions to air from rubber formulation and processing (0.6t). Emission reduction efficiency assumed to be 99%, giving 0.594t emission reduction.
	Applicability of measures: It is unknown to what extent thermal oxidisers or other air emissions abatement measures are already used or whether there are technical constraints in their application. We assumed that they could be applied in all cases.
	Specific measures taken forward: SCCP_R_5: Thermal oxidation
	Interactions with other measures: Could not be applied simultaneously with measures to replace SCCPs altogether. Could be applied with measures to reduce emissions to waste water.
	Main uncertainties and limitations: Extent to which thermal oxidation could be applied at the sites concerned is unknown and assumptions were made to illustrate the value of including a range of measures in the cost curve. Emission reduction efficiency will vary depending upon operational conditions and is subject to uncertainty.

Measure	Details of key elements of measure
Paints/coatings – use of alternatives	*One-off costs*: Total one-off costs for replacement of all uses based on RPA (2010) report which gives €205,000 to €769,000 for R&D and €418,000 to €916,000 for re-approval. Mid-point values give total of £962,000 in Sterling. Assuming amortisation period of five years gives equivalent annual cost of £213,000, which is assumed to be distributed proportionately amongst companies choosing different substitutes (see below). Total costs are for use as a whole in this application rather than per company.
	Recurring annual costs: Replacement with MCCPs costs €80/t; with LCCPs €200/t; with phthalates €300/t of SCCP replaced. All based on ECHA (2009c).
	Emissions reduced: All emissions from industrial application of coatings are removed with 100 per cent substitution (0.1t) (no other direct emissions). Additionally, assumed proportional reduction according to share of use in this application for emissions from manufacture and articles (3.01t combined). Total emission reduction = 3.11t.
	Applicability of measures: No information on which alternatives will be chosen by firms concerned. Assumed 80% of use is replaced with MCCPs, 10% LCCPs and 10% phthalates (own assumption to illustrate variety of options likely to be adopted and reflecting that different applications will require different substitutes).
	Specific measures taken forward: SCCP_P_6: Replacement with MCCPs SCCP_P_7: Replacement with LCCPs SCCP_P_8: Replacement with phthalates
	Interactions with other measures: None. No other measures considered for paints as total direct emissions from formulation, industrial application and consumer use are very small.
	Main uncertainties and limitations: - Data on costs of alternatives are relatively old and subject to uncertainty. - Data on one-off R&D costs do not take into account range of values quoted in RPA (2010). - Emission reductions are based on historical use and emissions (more recent data suggest current uses are lower but comparable emission data were not available). - Reduction in emissions from articles is only based on share of use, not relative emissions from specific articles concerned. Also assumes steady state is reached (emissions from articles would continue to occur for some years after use ceases).
Textiles – use of alternatives	*One-off costs*: Unknown
	Recurring annual costs: Total recurring costs for replacement of all uses based on RPA (2010) report which gives €0.23 (£0.19) per m^2 of coated textile for use of combined MCCP and deca-BDE based coating. Assumed that treated textile is 400 g/m^2 of which SCCP-based treatment is 140 g/m^2 (RPA, 2010). Assumed high proportion of coating is SCCP (50 per cent), giving 70 g/m^2 of SCCP. Based on 100t SCCP used in this application, 1.43 million m^2 would be required, with a cost of £274,000.

Measure	Details of key elements of measure
	Emissions reduced: All emissions from textile formulation and processing are removed with 100 per cent substitution (1.0t) (no other direct emissions). Additionally, assumed proportional reduction according to share of use in this application for emissions from manufacture and articles (3.0t combined). Total emission reduction = 4.0t.
	Applicability of measures: No information on which alternatives will be chosen by firms concerned.
	Specific measures taken forward: SCCP_T_9: Replacement with MCCP/deca-BDE based textile coating
	Interactions with other measures: Could not be applied in combination with measure to reduce emissions in waste water (see below).
	Main uncertainties and limitations: No information on R&D and other one-off costs available; could be significant. Emission reductions are based on historical use and emissions (more recent data suggest current uses are lower but comparable emission data were not available). Assumed high concentration of SCCPs in textile treatment compound (50 per cent). RPA report indicates could be as low as 10 per cent, which would imply higher substitution costs overall. Reduction in emissions from articles is only based on share of use, not relative emissions from specific articles concerned. Also assumes steady state is reached (emissions from articles would continue to occur for some years after use ceases).
Textiles – additional waste water treatment	*One-off costs*: Same as WWT for rubber (see above). Assumed three companies would apply.
	Recurring annual costs: Same as WWT for rubber (see above).
	Emissions reduced: Assumed to apply to all emissions to waste water from textile formulation and processing (1.0t). Emission reduction efficiency assumed to be 90 per cent, giving 0.9t emission reduction.
	Applicability of measures: It is unknown to what extent such water treatment techniques are already operational or whether there are technical constraints that would prevent GAC being applied. We assumed that it could be applied in all cases.
	Specific measures taken forward: SCCP_T_10: Additional waste water treatment (GAC)
	Interactions with other measures: Could not be applied simultaneously with measures to replace SCCPs altogether.
	Main uncertainties and limitations: Same as WWT for rubber (see above).
Sealants/ adhesives – use of alternatives	*One-off costs*: Total R&D costs for replacement of all uses based on RPA (2010) report which gives €50,000 to €100,000 per company (lower value taken here as higher value was worst-case). Of 20 companies, assumed seven had completed a quarter of R&D, seven completed half and six completed three-quarters so costs reduced proportionately, giving total costs of remaining R&D for all companies of £427,000, or £226,000 equivalent annual cost assuming costs are borne over two years.

Measure	Details of key elements of measure
	Recurring annual costs: Replacement with MCCPs costs €80/t; with LCCPs €200/t; with phthalates €300/t of SCCP replaced. All based on ECHA (2009c). Replacement with terphenyls cost €2,500/t (RPA, 2010).
	Emissions reduced: No quantified emissions from formulation, use or consumer use of sealants adhesives. Assumed proportional reduction according to share of use in this application for emissions from manufacture and articles (9.0t). Total emission reduction = 9.0t.
	*Applicability of measures***:** No information on which alternatives will be chosen by firms concerned. Assumed 70% of use is replaced with MCCPs, 10% LCCPs, 10% phthalates and 10% terphenyls (own assumption to illustrate variety of options likely to be adopted and reflecting that different applications will require different substitutes).
	*Specific measures taken forward***:** SCCP_S_11: Replacement with MCCPs SCCP_S_12: Replacement with LCCPs SCCP_S_13: Replacement with phthalates SCCP_S_14: Replacement with terphenyls
	Interactions with other measures: None. No other measures considered as no direct emissions from formulation and use.
	Main uncertainties and limitations: Data on costs of alternatives are relatively old and subject to uncertainty. Data on one-off R&D costs do not take into account range of values. Emission reductions are based on historical use and emissions (more recent data suggest current uses are lower but comparable emission data were not available). Reduction in emissions from articles is only based on share of use, not relative emissions from specific articles concerned. Also assumes steady state is reached (emissions from articles would continue to occur for some years after use ceases).

Note: Discount rate of four per cent and exchange rate of £1 = €1.20 (in 2010) have been used throughout.

Appendix C – Data for cost curve for deca-BDE

Note on prices

In the main report, information on costs of abatement measures is presented in 2010 Sterling values. This appendix may include cost data presented in other currencies and/or in prices from different years, particularly where the original data sources used different currencies. The conversions are included in the accompanying spreadsheets.

Characterisation of possible abatement measures

Substitution with alternatives for plastics

The most common reduction measure for deca-BDE releases is substitution with alternatives. Substitution of deca-BDE in a given polymer application can take place at three levels (Danish EPA, 2006):

- Deca-BDE can be replaced by another flame retardant with adequate properties without changing the resin.
- The plastic material, the resin with flame retardants and other additives, can be replaced by another plastic material (including copolymers) with adequate properties.
- The need for flame retardants can be eliminated by design changes, or the entire product can be replaced by a different product with adequate performance.

A number of reports were reviewed to identify current and future abatement measures that could be applied in the plastics and textiles industries for deca-BDE releases (European Commission, 2002; Denmark EPA, 2006; Illinois EPA, 2007; Illinois EPA, 2006; Lowell Center, 2005; Environment Agency, 2009; Defra, 2003). However, only a few reports included indicative cost data for alternatives; these are presented below.

An extensive list of alternative flame retardants for plastics in EEE is provided in a report by the Danish EPA (2006), including alternatives for enclosures, connectors and wires. However, no cost data were provided for these alternatives.

The report for Defra (2003) identified a number of potential substitutes for deca-BDE. The following table presents the potential substitutes and the evaluation that was presented in that report.

Table C1.1 Summary comparison of potential substitutes to deca-BDE and cost information (Defra, 2003)

	Applicability		Env. risks	Health risks	Relative cost
	Plastic	Textiles			Textiles
Tetrabromobisphenol-A	√		X	-	
Tetrabromophthalic andydride	√		?	?	
Ethane-1,2-bis (pentabromophenyl)	√	√	?	X	100% higher
Brominated polysterene	√		X	X	
Hexabromocyclododecane	√	√	X	X	50% higher
Tetradecabromodiphenoxybenzene	√		?	?	
Ethylene-bis(tetrabromophthalimide)	√		?	?	
Red phosphorus			X	?	
Ammonium polyphosphate		√	-	?	Similar
Tris(chloropropyl)phosphate	√		X	?	
N-hydromethyl-3-dimethylphosphonopririoamide		√	?	?	Costly (multi-stage)
Melamine	√		-	-	
Aluminium trihydroxide	√		(-)	(-)	

[1] The information on applicability only indicates that any one substance could be used for polymers and/or textiles (and not necessarily for all types of polymers or textiles). Applicability does not indicate superiority compared to deca-BDE.

[2] The symbols indicate: "(-)" no change compared to deca-BDE; "X" higher risks than those from deca-BDE; "?" insufficient information to compare with deca-BDE; "NA" not available.

For the EEE sector, a typical replacement scheme would be to use copolymers together with halogen-free organo-phosphorous compounds for enclosures (TVs) and other large parts, and to use other brominated flame retardants instead of deca-BDE for the small parts (below 25 g) in connectors, switches, and so on. Some organic phosphate ether alternatives are shown in the table below.

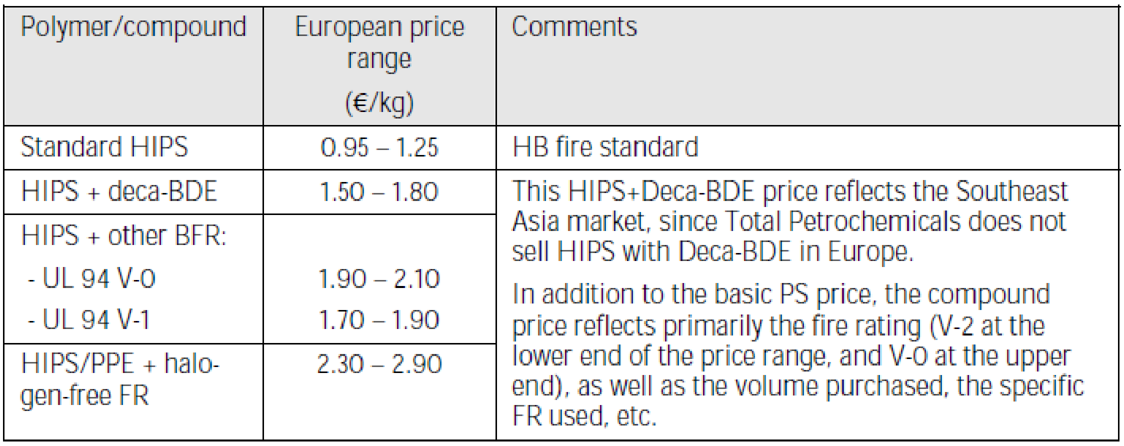
Table C1.2 Examples of organic phosphate esters flame retardants used instead of halogens in EEE (Danish EPA, 2006)

Substance	*CAS number*
DEEP, diethylethylphosphonate	*78-38-6*
DPK, diphenylcresylphosphate	*247-693-8*
RDP, resorcinol bis (diphenylphosphate)	*57583-54-7*
TEP, triethylphosphate	*78-40-0*
TCP, tricresylphosphate	*1330-78-5*
TPP, triphenylphosphate	*115-86-6*

The prices of the enclosures of copolymers with organo-phosphorous flame retardants (FRs) are about 60-70 per cent higher than HIPS with deca-BDE, corresponding to a price increase of the raw materials of an average television set with CRT technology (27.5-inch screen) of about €5. With typical total manufacturing costs of €300 for the average CRT television set, the difference in raw material costs corresponds to about two per cent (Danish EPA, 2006)[25]. A similar cost increase of 1.5-2.5 per cent in the total purchase price was also quoted in Lowell (2005). One potential issue of switching to phosphorus-based alternatives from deca-BDE is that, in case of fires, materials that have phosphorus-containing compounds may produce phosphine gas, which is not only an irritant but is also highly toxic, with known human fatalities due to accidental exposure from its use as a pesticide (Illinois EPA, 2006).

Further cost estimate comparisons for HIPS compounds were provided in the Danish EPA (2006) report.

Table C1.3 Indicative price levels of HIPS compounds (Danish EPA, 2006)



Polymer/compound	European price range (€/kg)	Comments
Standard HIPS	0.95 – 1.25	HB fire standard
HIPS + deca-BDE	1.50 – 1.80	This HIPS+Deca-BDE price reflects the Southeast Asia market, since Total Petrochemicals does not sell HIPS with Deca-BDE in Europe. In addition to the basic PS price, the compound price reflects primarily the fire rating (V-2 at the lower end of the price range, and V-0 at the upper end), as well as the volume purchased, the specific FR used, etc.
HIPS + other BFR:		
- UL 94 V-0	1.90 – 2.10	
- UL 94 V-1	1.70 – 1.90	
HIPS/PPE + halogen-free FR	2.30 – 2.90	

[1] UL 94 V-O and V-1 indicate flammability grades.

Using the prices of compounds in the table above, the extra cost of the alternative materials PPE/HIPS in an average television set would be about €5-6. The extra cost of using other BFRs would be €0.8-1.9 depending on the flammability grade. These estimated costs are for raw materials only. If the total production cost of a 27.5-inch TV set is roughly €300, the extra material cost of these alternatives is 0.5-2 per cent of the production cost, with the higher part of that range applicable to the halogen-free HIPS/PPE (similar to previous estimates for HIPS enclosures) (Danish EPA, 2006).

Substitution with alternatives for textiles

For textiles substitutes, Defra (2003) presented a qualitative comparison of the cost and effectiveness (defined in volume needed to achieve the required effect for flame retardancy) in textile finishing. The price comparison of the alternatives was as follows:

> Ammonium polyphosphate >> deca-BDE >> HBCD >> ethane-1,2-bis (pentabromophenyl) > micro-encapsulated ammonium polyphosphate

Conversely, the volume relationship (indicator of effectiveness) was as follows:

> Ethane-1,2-bis (pentabromophenyl) >>> micro-encapsulated ammonium polyphosphate >>> HBCD >> tetrakis hydroxymethyl phosphonate > N-hydromethyl-3-dimethylphosphonopririoamide >>> deca-BDE > ammonium polyphosphate

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[25] Any additional costs of research and development, and changes of moulds and other process equipment by the enclosure manufacturer, may be relatively small if substitution takes place coincidently with design changes and introduction of new products, such as TV sets with LCD screens or plasma display panels.

From this comparison it is obvious that deca-BDE is a relatively expensive option for the textile finisher, but it can provide the required flame retardant effect in small volumes, making it an attractive choice. The table in the previous section indicates the relative costs for textiles (where provided).

Substitution is less complicated with electronics enclosures compared to textiles, given the possible substitution approaches. Strategies for substituting deca-BDE in textiles include (Illinois EPA, 2007):

- redesign of products to reduce their fuel load by eliminating the use of foam (for example, in office chairs);
- application of other chemical flame retardants;
- incorporation of barrier layers in textile products;
- using inherently fire-resistant fabrics.

Identifying cost information for chemically-applied flame retardants is relatively straightforward. With regards to composite products such as mattresses and upholstered furniture, the substitution costs are complex for replacing deca-BDE backcoated fabric with a barrier layer or inherently flame-retardant fibre. The costs potentially involve several new materials such as fabric, barrier layer, foam, and other layers for comfort or performance characteristics and are generally not provided by the manufacturers (Lowell Center, 2005). Data from one manufacturer indicated that phosphate type replacements cost up to 2.5 times as much as deca-BDE for draperies.

Main findings and possible other measures

The previous section summarised a number of reduction measures (mainly alternatives) that have been or will be applied in the future, as well as other alternatives where R&D is ongoing. However, there is no information to estimate current baseline environmental releases from the plastics and textiles industries due to the following.

A number of alternatives were identified in the literature review that have been applied - or are technically feasible - in the plastics and textiles industries, including alternatives related to specific subsets and applications of deca-BDE, such as for the manufacture of mattresses. However, to our knowledge no data has been found indicating the breakdown of deca-BDE consumed in each of these subsets and applications, particularly in the plastics industry. Defra (2003) provided a rough breakdown of textiles applications in the UK, which was assumed to be similar to other EU countries: 80 per cent on upholstery, 15 per cent on blinds and five per cent on other uses.

Although an extensive list of alternatives for deca-BDE is available and well documented in the literature, no data indicates the current uptake of specific alternatives across sectors and in specific applications within those sectors.

For the development of more detailed baseline emissions (including the breakdown of emissions within subsectors and specific applications) that would take into account the current uptake of reduction measures, further investigations would be required, including detailed consultation with industry to collect more recent information and insight. This is outside the scope of the current work.

For the purposes of this study, generic information on potential measures to reduce emissions of deca-BDE from polymer and textile formulation and processing was used. This was based on information from other sources and is not necessarily specific to the sectors and companies involved (as described in the next section).

Data for incorporation into cost curves

The table below outlines the assumptions and data used in developing specific measures for the cost curve for deca-BDE.

Table C1.4 Summary of measures for inclusion in cost curve

Measure	Details of key elements of measure
Polymers – use of alternatives	*One-off costs*: Not known. No suitable quantitative estimates identified in the literature
	Recurring annual costs: HIPS with deca-BDE costs €1.5-€1.8/kg, HIPS with other BFR to UL 94 V-0 costs €1.9-€2.1/kg, HIPS with other BFR to UL 94 V-1 costs €1.7-€1.9/kg and HIPS/PPE + halogen-free FR costs €2.3-€2.9/kg (Danish EPA, 2006). Price increase calculated based on 10 per cent concentration in HIPS (EC, 2002) tonnage of deca-BDE used in this application and average of range of costs to calculate increased cost of non-deca-BDE alternatives.
	Emissions reduced: 0.2t based on emissions from all lifecycle stages in 2004 updated to the risk assessment (EC, 2004).
	Applicability of measures: Assumed could apply to all uses. Assumed one-third of the use is replaced by each of the three alternatives.
	Specific measures taken forward: Deca_P_1: Replacement of deca-BDE with other BFR to UL 94 V-0 in HIPS. Deca_P_2: Replacement of deca-BDE with other BFR to UL 94 V-1 in HIPS. Deca_P_3: Replacement of deca-BDE in HIPS with HIPS/PPE + halogen-free FR.
	Interactions with other measures: Could not be applied simultaneously with measures to reduce emissions from polymer compounding and conversion.
	Main uncertainties and limitations: Main uncertainties relate to which alternatives would be chosen in practice and what share of deca-BDE use would be replaced by each. Also, no estimates of R&D and other one-off costs are included so costs overall could be a significant underestimate.
Polymers – additional waste water treatment (tertiary)	*One-off costs*: Assumed €100,000 capital cost for granular activated carbon, based on range of €50,000 to €1,000,000 quoted in European Commission (2009). An amortisation period of 10 years was assumed. Assumed to be applied by 66 companies, based on Defra (2003).
	Recurring annual costs: Assumed to be €10,000 per year, or 10 per cent of capital cost.
	Emissions reduced: Assumed to apply to all emissions to waste water from polymer compounding and conversion (0.0065t). Emission reduction efficiency assumed to be 90 per cent, giving 0.0059t emission reduction.
	Applicability of measures: It is unknown to what extent such water treatment techniques are already used or whether there are technical constraints that would prevent GAC being applied. We assumed it could be applied in all cases.

Measure	Details of key elements of measure
	Specific measures taken forward: Deca_P_4: Additional waste water treatment (GAC).
	Interactions with other measures: Could not be applied simultaneously with measures to replace deca-BDE altogether (substitution). Could be applied with measures to reduce emissions to air.
	Main uncertainties and limitations: Extent to which GAC can be applied at the installations concerned is unknown and assumptions were made for the purposes of this pilot study to illustrate the value of including a range of different measures in the cost curve. Size and associated cost of GAC required is unknown. We assumed a relatively small unit. Emission reduction efficiency will depend on concentrations in waste water and other factors. The value assumed here is subject to uncertainty.
Polymers – abatement of emissions to air	One-off costs: €150,000 for thermal oxidiser based on Entec (2008). An amortisation period of 10 years was assumed. Assumed to be applied by 66 companies, based on Defra (2003).
	Recurring annual costs: Assumed to be €15,000 per year.
	Emissions reduced: Assumed to apply to all emissions to air from polymer compounding and conversion (0.081t). Emission reduction efficiency assumed to be 99 per cent, giving 0.080t emission reduction.
	Applicability of measures: It is unknown to what extent thermal oxidisers or other air emissions abatement measures are already applied or whether there are technical constraints in their application. We assumed they could be applied in all cases.
	Specific measures taken forward: Deca_P_5: Thermal oxidation.
	Interactions with other measures: Could not be applied simultaneously with measures to replace deca-BDE altogether (substitution). Could be applied with measures to reduce emissions to waste water.
	Main uncertainties and limitations: Extent to which thermal oxidation can be applied in practice at the installations concerned is unknown and assumptions were made for the purposes of this study to illustrate the value of including a range of measures in the cost curve. Emission reduction efficiency will vary depending upon operational conditions and is subject to uncertainty.
Textiles – use of alternatives	*One-off costs*: Not known. No suitable quantitative estimates identified in the literature.
	Recurring annual costs: Average price increase for use of alternative calculated to be £2.90 per kg. This is calculated from estimate that deca-BDE/antimony trioxide costs $US1.40 per lb and phosphorus (Pyromescent) $US3.00-$4.00 per lb. Exchange rate of $1.83/£ (in 2005, based on www.uktradeinfo.com) and inflation uplift of 1.145 (from 2005 to 2010 based on CPI from www.statistics.gov.uk).
	Emissions reduced: Emissions from all lifecycle stages from textiles, equivalent to 50.2t.

Measure	Details of key elements of measure
	Applicability of measures: Assumed could be applied to all uses of deca-BDE in textiles.
	Specific measures taken forward: Deca_T_6: Replacement of deca-BDE alternative flame retardant (phosphorus)’
	Interactions with other measures: Could not be applied simultaneously with measures to reduce emissions from textile installations.
	Main uncertainties and limitations: No estimates of R&D and other one-off costs are included so costs overall could be a significant underestimate. No information on what specific alternatives would be chosen in practice (cost estimate is based on an average value, also representing an average of other types of alternatives, as described in the supporting spreadsheet).
Polymers – additional waste water treatment (tertiary)	*One-off costs*: Assumed €100,000 capital cost for granular activated carbon, based on range of €50,000 to €1,000,000 quoted in European Commission (2009). An amortisation period of 10 years was assumed. Assumed to be applied by 40 companies, based on Defra (2003).
	Recurring annual costs: Assumed to be €10,000 per year, or 10 per cent of capital cost.
	Emissions reduced: Assumed to apply to all emissions to waste water from textile compounding and application (0.17t). Emission reduction efficiency assumed to be 90 per cent, giving 0.15t emission reduction.
	Applicability of measures: It is unknown to what extent such water treatment techniques are already used or whether there are technical constraints that would prevent GAC being applied. We assumed it could be applied in all cases.
	Specific measures taken forward: Deca_T_7: Additional waste water treatment (GAC).
	Interactions with other measures: Could not be applied simultaneously with measures to replace deca-BDE altogether (substitution).
	Main uncertainties and limitations: Extent to which GAC can be applied at the installations concerned is unknown and assumptions were made for the purposes of this pilot study to illustrate the value of including a range of different measures in the cost curve. Size and associated cost of GAC required is unknown. We assumed a relatively small unit. Emission reduction efficiency will depend upon concentrations in waste water and other factors. The value assumed here is subject to uncertainty.

Note: Discount rate of 3.5 per cent and exchange rate of £1 = €1.20 (in 2010) have been used throughout.

Appendix D – Data for cost curve for DEHP

Note on prices

In the main report, information on costs of abatement measures is presented in 2010 Sterling values. This appendix may include cost data presented in other currencies and/or in prices from different years, particularly where the original data sources used different currencies. The conversions are included in the accompanying spreadsheets.

Characterisation of possible abatement measures

Additional legislative controls

In the context of potential future emissions abatement under REACH, it is relevant to take into account reductions in emissions and/or use of DEHP that could be achieved through other legislative controls. This relates, in particular, to introducing further controls for manufactured articles such as food packaging, toys and medical devices.

The Risk Reduction Strategy considered further controls to improve protection of consumers, children and adults through potential amendments to existing directives. In particular, actions were considered with regard to the safety of toys, strengthening general product safety, considerations of a general ban on all types of uses of the substance or addressing specific areas of use. Further controls on the use of DEHP in identified medical devices, protection of workers' health and safety and in particular that of pregnant and breastfeeding workers were also considered.

Furthermore, measures to ensure safe disposal and increase recycling of PVC might be taken through European waste legislation. Similarly, the IPPC Directive could be amended, for instance, to extend the scope of relevant BREFs to include considerations specific to DEHP.

The Water Framework Directive Supporting Plan for DEHP in the UK considered, for example, prohibition of the use of DEHP for pipes and products in contact with water and further measures under IPPC (implementation of BAT plus other potential measures) for the chemical industry and for paper and pulp industry, although the costs of these measures were not estimated.

Removal of DEHP-containing plastic water hoses and flooring from domestic and commercial properties (such as those less than five years old) was another measure considered. The unit costs of this measure were estimated to be £5.2 -£10.4 million per kg of DEHP removed.

Control of spillovers during production of DEHP and during production of (non-) polymers is another potential source control measure. While no cost data are available in the literature reviewed, the SOCOPSE[26] study suggests that the costs of controlling spillovers during production of (non-) polymers are expected to be high as recovery of small fractions of substances is often expensive.

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[26] Source control of priority substances in Europe (http://www.socopse.se/).

Use of phthalate and non-phthalate alternative materials

In order to abate environmental releases of DEHP, particularly at the use and disposal stages of its lifecycle:

- in some cases, DEHP can be replaced with an alternative phthalate substance;
- other (non-phthalate or non-PVC) materials can be used in some applications.

Both measures are technically feasible as a range of phthalate and non-phthalate alternatives are available to replace DEHP in some applications. In fact, the decrease in production volumes in recent years reflects the fact that DEHP, for many applications, has been replaced by other substances, primarily di-isononyl phthalate (DINP). Furthermore, for some applications the plasticised PVC has been replaced with other materials.

The main alternatives to DEHP have been the two phthalates: di-isononyl phthalate (DINP) and di-isodecyl phthalate (DIDP). DEHP has to a large extent been replaced by DINP or DIDP in synthetic (PVC) leather for upholstery, in toys and products for babies and in soft PVC for medical applications. Since 2000, DINP and DIDP have dominated marketed PVC flooring, wall coating and carpets with PVC backcoating. Similarly, a range of alternatives are available for non-PVC applications.

Table D1.1 Examples of alternative plasticisers by application area

Application area	**Alternative plasticisers**
Coil coated roofing	DIDP, polyurethane, polyester
Fabric coating	DIDP, DINP
Floor and wall coating	DINP, polyolefins
Cable	DIDP or other phthalates
Foil	DIDP
Profiles	DINP

[1] Swedish Chemicals Inspectorate (2006).

For medical devices, alternative plasticisers include ATBC, COMGHA, BTHC, DEHA, DINCH, DINP, DOTP, TOTM. However, substances proposed or used for substitution should exhibit lower (or equal) hazard compared to DEHP; for instance, COMGHA also causes reproductive toxicity but in much higher doses than DEHP (SCENIHR, 2008).

Several non-PVC based materials could be effective in medical devices. Use of non-phthalate plasticisers is particularly relevant where the risk of human exposure is particularly high, such as in toys and childcare articles, medical devices, food packaging and water mattresses. Alternatives marketed for these product groups include, among others, adipates, citrates, carboxylates, alkylsulfonic acid ester and castor oil derivatives.

Very few of the alternatives have been subject to a comprehensive analysis of environmental, health, feasibility and financial suitability. Overall, DINP, DEHT, BTHC, DINCH and ASE are among the most widely used alternatives at present and/or are promising alternative substances from a health and environmental perspective. The suitability of these substances for different applications is highlighted in the table below.

Table D1.2 Suitability of alternative plasticisers in certain applications

Name	DINP	DEHT	BTHC	DINCH	ASE
Flooring and wall covering	X	X			
Film/sheet and coated products	X	X		X	X
Medical products			X	X	
Wire and cable	X				
Coated fabric and footwear		X		X	X
Toys		X			X
Automotive	X				
Non-polymer applications:					
Adhesives				X	X
Printing ink				X	X
Sealants	x				X

[1] ECHA (2009a).

In terms of costs, DEHP producers and downstream users will be affected. DEHP substitution will result in costs to DEHP producers; however, it is suggested that much of the manufacturing capacity can probably be converted to produce alternative plasticisers or other chemicals. In the case of medical equipment, there will be additional costs to comply with regulatory procedures for introducing new materials in medical devices. No estimates of the one-off costs of such conversions were found.

Downstream users will also be affected by any increase in material costs as well as by any development work needed, such as work on developing new formulations, changes in manufacturing, including processes, testing for conformity with regulatory, industry and other standards. No estimates of the one-off costs of such conversions were found associated with these changes.

According to COWI *et al.* (2009) the alternatives are, in general, more expensive than DEHP with DEHT being the least expensive alternative at an incremental cost of about 10 per cent. The table below highlights the cost difference for a number of alternative plasticisers.

Table D1.3 Costs of selected alternatives to DEHP in PVC

Name	Costs of substance €/kg	Substitution factor	Normalised cost as per cent of DEHP
DEHP	1.21	1	100
DINP	1.28	1.06	112
DIDP	1.34	1.1	121
DEHT	1.28	1.03	109
BTHC	2.00	0.975	160
DINCH	1.58	Unknown	nd
ASE	nd	nd	nd

[1] ECHA (2009a).

[2] Substitution factor relates to differential in quantity used for substitute compared to DEHP.

In the Risk Reduction Strategy for DEHP, it was estimated that replacing DEHP in PVC applications for use outdoors would cost less than 0.6 per cent of the turnover of the relevant industry segment. In the case of more specialised uses in medical devices, the annual costs of substitution were estimated to be below €50 million. In particular, the costs of substituting DEHP were assessed for non-specialised applications such as footwear, based on the assumption that it would be substituted with DINP which is eight per cent more expensive than DEHP (which in turn costs €850 per tonne).

The costs of substitution were also assessed in the case of specialised applications, such as medical equipment, where – compared to non-specialised uses – the choice of alternative needs to be more use-specific. Relative increases in cost of raw materials are also likely to be more significant for these applications. The plasticiser cost for likely alternatives is estimated to be somewhere between two and six times higher than that of DEHP, depending on the specific use. With a price of DEHP of €850/t, this gives an increase in raw material cost of between €850/t and €4,200/t of DEHP substituted.

However, the estimate is likely to mask a significant variety. For example, the cost increase of substituting PVC in gloves for medical uses with nitrile rubber (which does not contain phthalates) is 30 per cent. In the case of feeding-tubes, the cost of a DEHP-based alternative was estimated to be the same as for DEHP-containing tubes.

In addition to the replacement of DEHP with other plasticisers, the soft PVC itself may be replaced with other materials where, for many applications of DEHP/PVC, alternative materials exist at similar prices. Many of the materials seem to have equal or better environmental, health and safety performance and cost profiles (although the literature indicates that a fuller lifecycle analysis may be required to confirm this).

The table below highlights estimated costs of various alternatives from the SOCOPSE study. As compared to the preceding information (from the ECHA report), this shows that there is significant variability amongst cost estimates, as well as significant variability in terms of the types of alternatives that can be used.

Table D1.4 Costs of selected alternatives to DEHP (from SOCOPSE)

Name	Normalised cost as percent of DEHP
Bulk phthalates	100
Benzoates	150-400
Citrates	350
Phosphates	400-500
Alkylsulfonates	200-250
Polymers	200-500
DINCH	150
Eastman 168	>150
Soft-n-Safe	300 to 400
Isosorbide	150 to 200

[1] SOCOPSE (2009).

The technical lifetime of DEHP-containing products is typically between five and 30 years, as outlined in the table below.

Table D1.5 Technical lifetime of some products in which DEHP is used

Areas of application	Technical lifetime in years
Indoor use	
Coated products	7
Film/sheet	7
Hoses and profiles	10
Floors	20
Adhesives and sealant	20
Cables	30

Areas of application	Technical lifetime in years
Lacquers and paints	7
Printing ink	1
Outdoor uses	
Roofing material	20
Roofing (coil coating)	10
Cables	30
Coated fabric	10
Hoses and profiles	10
Car undercoating	12
Shoe soles	5
Adhesives and sealant	20
Lacquers and paints	7

[1] European Commission (2008).

End-of-pipe controls

End-of-pipe measures are another set of viable options to abate emissions of DEHP.

Potential abatement measures at industrial installations may include process-integrated measures and/or end-of-pipe treatment. Process-integrated measures reduce emissions at source and could include, for example, optimisation of process steps or technical adaptations to the process, reducing the amount of waste water and gas and/or pollutants in the waste. The emissions of DEHP from industrial processing have been allocated half to air and half to water in previous risk assessments.

The Risk Reduction Strategy for DEHP includes consideration of a variety of potential measures for abating emissions to water and air.

Emissions to water are mostly occasional and occur as machinery is cleaned. In some cases (a fifth) there are assumed to be continuous emissions to waste water; in these cases the waste water is either sent for treatment or treated on site. Preventing emissions of DEHP during cleaning and related activities should be possible by adapting work procedures to minimise emissions and exposure to workers, for example by emptying (as far as possible) the equipment of DEHP before washing with water. The closing of the cooling water loop will also, in most cases, be a fairly simple and low-cost measure. The incremental costs for water treatment are likely to be significantly lower than the costs for air treatment.

However, if tertiary waste water treatment is required, this can impose significant costs. SOCOPSE (2009) considers the following options for waste water treatment:

- Main treatment WWTP optimisation: Removal efficiency of DEHP is 80-90 per cent. The additional investment costs are expected to be minimal, though good inoculants could be expensive. The measure will involve further labour costs.
- Secondary sludge treatment and reuse: Removal efficiency is 21-62 per cent for DEHP (common anaerobic digestion of secondary waste sludge). Additional investment costs would be required to adjust the treatment method but these are highly site-specific.

Advanced (tertiary) water treatment:

- Membrane filtration: removal efficiency is above 90 per cent (in most cases above 97 per cent). For a capacity between 200-1,000 m^3/h, the treatment costs for nanofiltration and reverse osmosis vary between €0.18 and €0.68 per m^3 depending on the flux and recovery rate. This does not include the cost of discharge or treatment of the concentrate. Most membranes have a lifetime of around five years. Depending on the scale of installation, replacement costs are in the order of €15-25/m^2 membrane for capacities of between 200 and 1,000 m^3/h (DHV, 2002). Installations using DEHP are likely to lie towards the bottom end of this range.

- Ozone oxidation: Removal efficiency is around 80 per cent. The costs of ozone treatment depend on the quality of the water (organic load) and contact time for oxidation. For DEHP, for removal of 80 per cent with a 30-minute contact time, treatment costs are estimated at €0.05-€0.10 per m^3 for capacities between 200 and 1,000 m^3/h. For the combination of ozone and UV, the treatment costs are estimated at €0.06-€0.11 per m^3 for capacities between 200 and 1,000 m^3/h. However, these estimates are highly dependent on site-specific conditions. Installations using DEHP are likely to lie towards the bottom end of this range.
- UV irradiation, photo-Fenton and UV/hydrogen peroxide oxidation: the costs of UV treatment depend on the quality of water, UV-absorbance of the specific contaminant (DEHP) and contact time but these have not been quantified.
- Activated carbon: the cost of powdered activated carbon (PAC) is estimated to be €2.0-2.5 per kg. For removal of 50-80 per cent, the costs for PAC range from €0.010 to €0.015 per m^3. Total costs are estimated to be €0.015 to €0.020 per m^3 including dosing equipment but excluding a filtration/sedimentation step that is needed to remove the PAC. The costs for filtration/sedimentation have to be added if PAC-treatment cannot be integrated into an existing treatment system. The treatment costs of GAC depend on the quality of the water (organic load) and the contact time for removing the contaminant. The treatment cost for a contact time of between 10 and 20 minutes is estimated to be €0.10-€0.15 per m^3 for capacities between 200 and 1,000 m^3/h[27].

Based on data from UKWIR, installing tertiary treatment with GAC would amount to around £1.25 million annualised costs per STW with unit abatement costs of £6.5 million per kg. Introduction of tertiary treatment is one of the most suitable potential further measures, in particular further removal of DEHP with granulated activated carbon (GAC), for which the mean removal rate is assumed to be around 99 per cent.

The choice of a waste gas treatment technique is highly site-specific. Overall, biofiltration, coolant condensation and thermal oxidation constitute viable options. These technologies, when properly applied, will reduce emissions by more than 90 per cent. Of the three technologies that will be assessed, the total costs (capital and operating) are highest for thermal oxidation (incineration), lowest for biofiltration, with the costs for condensation in between. These are illustrated in the table below.

Table D1.6 Costs of techniques for abatement of DEHP emissions

Technology	Capital costs (€)	Operational cost (€/year)
Biofiltration	5,000 to 20,000	750 to 1,500
Coolant condensation	5,000	Two man-hours/week plus one man-day/year
Thermal oxidation (straight or regenerative)	10,000 to 50,000	2,200 to 6,500

[1] Swedish Chemicals Inspectorate (2006).

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[27] Other sources of information indicate that ozone oxidation could be significantly less expensive than activated carbon, whereas the figures presented here (based on the IPPC BREF Note) suggest the opposite. In practice, costs will vary significantly amongst installations and according to technologies and suppliers used. In addition, wide ranges of estimated costs are presented in the literature, leading to additional uncertainties.

Data for incorporation into cost curves

The table below outlines the assumptions and data used in developing specific measures for the cost curve for DEHP.

Table D1.7 Summary of measures for inclusion in cost curve

Measure	**Details of key elements of measure**
Waste gas treatment: biofiltration (information source: Swedish Chemicals Inspectorate, 2006)	*One-off costs*: €5,000-20,000 with a mid-point of €12,500 or £10,400 per company. Lifetime assumed: 10 years.
	Recurring annual costs: €750-1,500 per year per company with the average estimate €1,130 or £900.
	Emissions reduced: All air emissions from manufacturing, formulation and processing removed with 90% efficiency.
	Applicability of measures: No information on the current level of treatment – 100% assumed (own assumption).
	Specific measures taken forward: BBAU 4: Waste gas treatment: biofiltration (manufacturing) BBAU 10: Waste gas treatment: biofiltration (formulation and processing).
	Interactions with other measures: Could not be applied simultaneously with alternative measures to abate air emissions from DEHP manufacturing, formulation and processing, BBAU 5, 6, 11, 12. Cannot be applied fully with BBAU16-23 (substitution).
	Main uncertainties and limitations: One-off, operating and maintenance costs are average values that are applied to manufacturing companies (seven) and sites involved in formulation/processing (800). Emission reductions and costs may be overestimated as it is assumed that the abatement is not currently applied.
Waste gas treatment: coolant condensation (information source: Swedish Chemicals Inspectorate, 2006)	*One-off costs*: €5,000 or £4,200 per company. Lifetime assumed: 10 years.
	Recurring annual costs: €1,685 per year per company (based on time inputs above and Eurostat wage rates) or £1,400.
	Emissions reduced: All air emissions from manufacturing, formulation and processing removed with 90% efficiency.
	Applicability of measures: No information on the current level of treatment – 100% assumed (own assumption).
	Specific measures taken forward: BBAU 5: Waste gas treatment: coolant condensation (manufacturing) BBAU 11: Waste gas treatment: coolant condensation (formulation and processing).
	Interactions with other measures: Could not be applied simultaneously with alternative measures to abate air emissions from DEHP manufacturing, formulation and processing, BBAU 4, 6, 10, 12. Cannot be applied fully with BBAU16-23 (substitution).

Measure	Details of key elements of measure
	Main uncertainties and limitations: One-off, operating and maintenance costs are single point values that are applied to manufacturing companies (seven) and sites involved in formulation/processing (800). Emission reductions and costs may be overestimated as it is assumed that the abatement is not currently applied.
Waste gas treatment: thermal oxidation (straight or regenerative) (information source: Swedish Chemicals Inspectorate, 2006)	*One-off costs*: €10,000-50,000 with a mid-point estimate of €30,000 or £25,000 per company. Lifetime assumed: 10 years.
	Recurring annual costs: €2,200-6,500 per year per company with the average estimate - €4,400 or £3,700.
	Emissions reduced: All air emissions from manufacturing, formulation and processing removed with 90% efficiency.
	*Applicability of measures***:** No information on the current level of treatment – 100% assumed (own assumption).
	*Specific measures taken forward***:** BBAU 6: Waste gas treatment: thermal oxidation (straight or regenerative) (manufacturing) BBAU 12: Waste gas treatment: thermal oxidation (straight or regenerative) (formulation and processing).
	Interactions with other measures: Could not be applied simultaneously with alternative measures to abate air emissions from DEHP manufacturing, formulation and processing, BBAU 4, 5, 10, 11. Cannot be applied fully with BBAU16-23 (substitution).
	Main uncertainties and limitations: One-off, operating and maintenance costs are average values that are applied to manufacturing companies (seven) and sites involved in formulation/processing (800). Emission reductions and costs may be overestimated as it is assumed that the abatement is not currently applied.
Advanced (tertiary) water treatment: membrane filtration (information source: EC, 2009 and SOCOPSE, 2009)	*One-off costs*: €450-1,500 per m^2 of membrane with average costs of 950 per m^2. Total one-off costs are £330,000 per company. Lifetime assumed: 10 years Total costs calculated based on an assumed capacity of WWTP of 1,000 m^3/day (based on the information on WWTP capacities for 43 chemical industrial sites (EC, 2009)) and the calculated membrane area required, 417 m^2. The area is calculated based on crossflow speed - 3.5 m/s (average); permeate flow - 100 litres per m^2 membrane area per hour (EC, 2009) and capacity.
	Recurring annual costs: €80-350 per m^2 per five years with an average cost of €215 per m^2 per five years. Total recurring annual costs £18,000 per company per year (calculated 417 m^2 multiplied by €215 divided by five years and applied exchange rate).
	Emissions reduced: All waste water emissions from manufacturing, formulation and processing are removed with 94 per cent efficiency.

Measure	Details of key elements of measure
	Applicability of measures: No information on the current level of treatment For manufacturing, formulation and processing – 100% assumed (own assumption). For use – Eurostat data on the number of WWTP in the EU and the level of current treatment is used: two-thirds (or 33,100 WWTPs) do not currently have advanced waste water treatment.
	Specific measures taken forward: BBAU 1: Advanced (tertiary) water treatment. Membrane filtration (manufacturing) BBAU 7: Advanced (tertiary) water treatment. Membrane filtration (formulation and processing) BBAU 13: Advanced (tertiary) water treatment. Membrane filtration (use).
	Interactions with other measures: Could not be applied simultaneously with alternative measures to abate waste water emissions from DEHP manufacturing, formulation and processing and use BBAU 2, 3, 8, 9, 14, 15. Cannot be applied fully with BBAU16-23 (substitution).
	Main uncertainties and limitations: One-off costs are average values applied to manufacturing, formulation, processing and use based on the assumed average capacity and number of the sites involved. Operating and maintenance costs are a range per m^3 for different sizes of the membrane (and hence capacities) – average costs and assumed average capacity are applied to manufacturing companies (seven), formulation/processing sites and public WWTPs. Assuming 100 per cent application rate for manufacturing and formulation/processing is likely to overestimate the emission reductions.
Advanced (tertiary) water treatment: ozone oxidation (information source: EC, 2009 and SOCOPSE, 2009)	*One-off costs*: €10,000-100,000 for capacities between one m^3 and 10,000 m^3 per day. Total one-off costs are £8,333,000 per company. Lifetime assumed: 10 years. Total costs calculated based on an assumed capacity of WWTP of 1,000 m^3/day (based on information on WWTP capacities for 43 chemical industrial sites (EC, 2009)).
	Recurring annual costs: annual costs are below €0.05 per m^3 or £15,000 per company per year. Calculated €0.05 multiplied by 365,000 m^3 per year divided by exchange rate.
	Emissions reduced: All waste water emissions from manufacturing, formulation and processing are assumed to be removed with 80 per cent efficiency.
	Applicability of measures: For manufacturing, formulation and processing – 100% assumed (own assumption). For use – Eurostat data on the number of WWTP in the EU and the level of current treatment is used: two-thirds (or 33,100 WWTPs) do not currently have advanced waste water treatment.

Measure	Details of key elements of measure
	Specific measures taken forward: BBAU 2: Advanced (tertiary) water treatment. Ozone oxidation (manufacturing) BBAU 8: Advanced (tertiary) water treatment. Ozone oxidation (formulation and processing) BBAU 14: Advanced (tertiary) water treatment. Ozone oxidation (use).
	Interactions with other measures: Could not be applied simultaneously with alternative measures to abate waste water emissions from DEHP manufacturing, formulation and processing and use, BBAU 1, 3, 7, 9, 13, 15. Cannot be applied fully with BBAU16-23 (substitution).
	Main uncertainties and limitations: One-off costs are average values applied to manufacturing, formulation, processing and use based on the assumed average capacity and number of the sites involved. Assuming 100% application rate for manufacturing and formulation/processing is likely to overestimate the emission reductions.
Advanced (tertiary) water treatment: activated carbon (information source: EC, 2009 and SOCOPSE, 2009)	*One-off costs*: €50,000-1,000,000 with average costs of €525,000 or £437,500 per company. Lifetime assumed: 10 years
	Recurring annual costs: annual costs are below €0.5 per m^3 for capacity of 1,000 m^3/day or £152,000 per company per year. Calculated €0.5 multiplied by 365,000 m^3 per year divided by relevant exchange rate (capacity of WWTP assumed to be 1,000 m^3/day based on the information on WWTP capacities for 43 chemical industrial sites (EC, 2009)).
	Emissions reduced: All air emissions from manufacturing, formulation and processing removed with 65% efficiency.
	Applicability of measures: For manufacturing, formulation and processing – 100% assumed (own assumption). For use – Eurostat data on the number of WWTP in the EU and the level of current treatment is used: two-thirds (or 33,100 WWTPs) do not currently have advanced waste water treatment.
	Specific measures taken forward: BBAU 3: Advanced (tertiary) water treatment. Activated carbon (manufacturing) BBAU 9: Advanced (tertiary) water treatment. Activated carbon (formulation and processing) BBAU 15: Advanced (tertiary) water treatment. Activated carbon (use).
	Interactions with other measures: Could not be applied simultaneously with alternative measures to abate waste water emissions from DEHP manufacturing, formulation and processing and use, BBAU 1, 2, 7, 8, 13, 14. Cannot be applied fully with BBAU16-23 (substitution).

Measure	Details of key elements of measure
	Main uncertainties and limitations: One-off costs are average values that are applied to manufacturing, formulation, processing and use based on the number of the sites involved. Assuming 100% application rate for manufacturing and formulation/processing is likely to overestimate the emission reductions.
Substitution of DEHP in use in film/sheet and coated products made by calendaring with DIDP	*One-off costs*: there is no information on R&D costs.
	Recurring annual costs: Price of DIDP – €1.34 per kg (£1,120 per tonne), substitution factor 1.1. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	Applicability of measures: No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	Specific measures taken forward: BBAU 16: Substitution of DEHP in use in film/sheet and coated products made by calendaring with DIDP.
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100 per cent while the comparative price of substitute substances represents a single point estimate and may not be up to date,. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.
Substitution of DEHP in hoses and profiles with DINP	*One-off costs*: no information is available on R&D costs.
	Recurring annual costs: costs €1.28 per kg; substitution factor 1.06; normalised cost as per cent of DEHP 112 per cent. Cost of the substitute is £1,070 per tonne. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.

Measure	Details of key elements of measure
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	*Applicability of measures***:** No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	*Specific measures taken forward***:** BBAU 17: Substitution of DEHP in hoses and profiles with DINP.
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore, partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100 per cent while the comparative price of substitute substances represents a single point estimate and may not be up to date. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.
Substitution of DEHP in flooring and wall coating with DINP	*One-off costs*: no information is available on R&D costs.
	Recurring annual costs: costs €1.28 per kg; substitution factor 1.06; normalised cost as per cent of DEHP 112 per cent. Cost of the substitute is £1,070 per tonne. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	*Applicability of measures***:** No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	*Specific measures taken forward***:** BBAU 18: Substitution of DEHP in flooring and wall coating with DINP.

Measure	Details of key elements of measure
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100% while the comparative price of substitute substances represents a single point estimate and may not be up to date. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.
Substitution of DEHP in coil coated roofing with DIDP	*One-off costs*: there is no information on R&D costs.
	Recurring annual costs: Costs €1.34 per kg; substitution factor 1.1; normalised cost as per cent of DEHP 121 per cent. Cost of the substitute is £1,120 per tonne. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	Applicability of measures: No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	Specific measures taken forward: BBAU 19: Substitution of DEHP in coil coated roofing with DIDP.
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100% while the comparative price of substitute substances represents a single point estimate and may not be up to date. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.

Measure	**Details of key elements of measure**
Substitution of DEHP in wires and cables with DINP	*One-off costs*: there is no information on R&D costs.
	Recurring annual costs: Costs €1.28 per kg; substitution factor 1.06; normalised cost as per cent of DEHP 112 per cent. Cost of the substitute is £1,070 per tonne. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	Applicability of measures: No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	Specific measures taken forward: BBAU 20: Substitution of DEHP in wires and cables with DINP.
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100% while the comparative price of substitute substances represents a single point estimate and may not be up to date. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.
Substitution of DEHP in footwear with DEHT	*One-off costs*: there is no information on R&D costs.
	Recurring annual costs: Costs €1.28 per kg; substitution factor 1.06; normalised cost as per cent of DEHP 112 per cent. Cost of the substitute is £1,070 per tonne. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.

Measure	Details of key elements of measure
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	Applicability of measures: No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	Specific measures taken forward: BBAU 21: Substitution of DEHP in footwear with DEHT.
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100% while the comparative price of substitute substances represents a single point estimate and may not be up to date. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.
Substitution of DEHP in coated fabric with DEHT	*One-off costs*: there is no information on R&D costs.
	Recurring annual costs: Costs €1.28 per kg; substitution factor 1.06; normalised cost as per cent of DEHP 112 per cent. Cost of the substitute is £1,070 per tonne. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	Applicability of measures: No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	Specific measures taken forward: BBAU 22: Substitution of DEHP in coated fabric with DEHT.

Measure	**Details of key elements of measure**
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore, partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100% while the comparative price of substitute substances represents a single point estimate and may not be up to date. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.
Substitution of DEHP in lacquers and paints with DINCH	*One-off costs*: there is no information on R&D costs.
	Recurring annual costs: Costs €1.58 per kg; substitution factor unknown (assumed 1.0); normalised cost as per cent of DEHP unknown. Cost of substitute is £1,300 per tonne. The incremental costs are calculated by multiplying the price of the substitute by DEHP use in the relevant application (tonnage) and by the substitution factor minus the price of DEHP multiplied by the use volume. Recurring costs are not per company but for the total quantity substituted.
	Emissions reduced: All air, wastewater, soil and solid waste emissions from use are removed with 100% efficiency. Emission reduction from manufacturing, formulation and processing is calculated based on the data on the DEHP used in the relevant processing and formulation stages and based on the assumption of proportional reduction according to share of use in this application for emissions from manufacture.
	Applicability of measures: No information on the current level of substitution – 100% assumed of the relevant application (own assumption).
	Specific measures taken forward: BBAU 23: Substitution of DEHP in lacquers and paints with DINCH.
	Interactions with other measures: the reduction achieved in the other lifecycle stages, e.g. manufacturing, formulation and processing could be abated with waste water and waste gas treatment techniques. The measure therefore partially could not be applied simultaneously with BBAU 1-15.
	Main uncertainties and limitations: One-off costs are not available; no assumption was made. The rate of substitution may not be 100% while the comparative price of substitute substances represents a single point estimate and may not be up to date. For manufacturing, emission reduction is calculated based on the proportion of use rather than data on emissions associated with the DEHP further used in the applications under consideration.

Note: Discount rate of 3.5 per cent and exchange rate of £1 = €1.20 (in 2010) have been used throughout.

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