Economic Evaluation of PVC Waste Management

A report produced for European Commission Environment Directorate

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Executive Summary

AEA Technology, in collaboration with Metroeconomica, were contracted by European Commission DG Environment to undertake this assessment of the waste management costs of diverting PVC waste away from incineration (and in particular, towards recycling) and the associated environmental costs and benefits.

The study covers the EU-15 and the first six Accession Countries over the period 2000 to 2020. Over this period post-consumer PVC waste (accounting for 88% of all PVC waste) is expected to increase from 3.6 to 6.4 million tonnes per year across this group of countries. Recycling rates for these wastes are very low at only 3% of arisings, reflecting high separation and processing costs. The remaining 12% of the total volume of PVC waste is *pre-consumer* waste. This was excluded from the study because lower collection and processing costs already lead to a high rate of recycling (85%).

PVC is available in rigid and flexible (plasticised) forms, the latter accounting for 70% of post-consumer PVC waste at the present time. This share is expected to fall to about 58% by 2020, fuelled by the use of rigid material in the construction industry. This has consequences for the present study for two reasons. Firstly, there are differences in the ease and hence cost of recycling different types of waste. Second, there are differences in chemical formulation, and thus in the burdens imposed on the environment.

Under current conditions 82% of waste PVC goes to landfill, and 15% to incineration. However, restrictions on landfill from initiatives at both EU and Member State level mean that this is likely to change, and by 2020 incineration is expected to account for perhaps as much as 45% of arisings. Under current legislation, forming the business as usual (BAU) scenario adopted here, a further 9% is estimated as likely to go to mechanical recycling, leaving about 50% destined for landfill.

The analysis presented in this report is based on three scenarios. In the first and second of these, recycling rates increase to 15% and 22% respectively, with proportionate decreases in the amount of PVC sent to incineration and landfill. In the third scenario recycling rates are unchanged against BAU, but incineration rates increase to 27% to 30% as a result of the diversion of constructional wastes to landfill, compared with up to 45% incineration forecast under BAU.

The chlorine content of PVC places a high demand on the use of alkaline reagents in air pollution control systems at incinerators, depending on the type of air pollution control technology employed. Each unit of PVC incinerated requires the same amount of these reagents as up to 70 units of MSW, for the average mix of air pollution abatement systems. This in turn increases the amount of residue generated and requiring disposal. These specific costs of PVC incineration (net of energy revenues) amount to some €165/tonne for rigid PVC and € 85/tonne for flexible material, for the average estimated mix of air pollution control systems. Given that these costs are spread across all material sent for incineration, rather than being allocated specifically to loads by PVC content, it can be seen that the additional cost of incinerating PVC is currently paid by incineration of other materials. This effectively subsidises PVC waste incineration. These additional costs paid indirectly by all users of the incinerator are referred to in this study as the ‘incinerator subsidy’.

In estimating the costs of achieving the scenarios, the following cost elements were considered:

Scenarios 1 and 2		Scenario 3
Incineration ➔ Recycling	**Landfill ➔ Recycling**	**Incineration ➔ Landfill**
Avoided costs		
➢ 'Incinerator subsidy' ➢ Incinerator charges	➢ Landfill charges	➢ 'Incinerator subsidy' ➢ Incinerator charges
Incurred costs		
➢ Recycling costs	➢ Recycling costs	➢ Costs of additional sorting for diversion to landfill ➢ Landfill charges
Net costs		
➢ Sum of avoided and incurred costs		

The total present value net cost of the scenarios in terms of support needed for recycling is shown in the following table, with and without the avoided 'incinerator subsidy'. Negative values represent cost savings. The table also shows annualised costs and average cost per tonne of waste diverted.

Present value financial costs for the EU-21 of diverting PVC (4% discount rate). Negative figures represent savings. The ranges correspond with the results for alternative 'high' and 'low' incineration futures investigated under the scenarios.

4% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Average total PVC waste diverted, million tonnes2000-2020 **From landfill** **From incineration**	**4.5 to recycling** **2.68-2.91** **1.60-1.83**	**9.76 to recycling** **5.7-6.22** **3.55-4.07**	**9.6-11.0 to landfill** **-** **9.6-11.0**
Total costs, million €			
Excluding 'incinerator subsidy'	372 to 381	2,179 to 2,200	-203 to -235
Including 'incinerator subsidy'	199 to 230	1,839 to 1,903	-882 to –1,019
Annualised costs, million € /year			
Excluding 'incinerator subsidy'	27 to 28	160 to 162	-15 to -17
Including 'incinerator subsidy'	15 to 17	135 to 140	-65 to -75
Cost per tonne diverted € /tonne			
Excluding 'incinerator subsidy'	82 to 84	223 to 225	-21
Including 'incinerator subsidy'	44 to 51	188 to 194	-92

The outcome of scenarios 1 and 2 are strongly dependent on net recycling costs, which are charged to waste producers as a disposal fee for recycling. When revenue from the sale of recyclate is low, the disposal fee increases, and vice versa. For high quality recycling, in which recyclate substitutes for virgin compound, the maximum price of recyclate is set by the price of virgin compound, as well as by the quality of the recyclate. Costs of collection and segregation of waste prior to processing through recycling facility make up a major component of recycling costs. These mobilisation costs vary markedly between waste streams and PVC products. Unit costs are lowest in scenario 1, where recycling is focussed on relatively easy to process products from constructional applications, and highest in scenario 2 where maximum rates of recycling from a range of applications is assessed. In the case of scenario 3, net cost savings result from diversion from incineration to landfill (excluding the 'incinerator subsidy') when the additional present value costs of sorting for diversion to landfill are less than ~€ 40/tonne. The average cost of € 30/tonne used in this study equates to a present value of € 20/tonne for the additional sorting step. Implementation of scenario 3 would, however, require changes in legislation to allow PVC waste to be diverted to landfill in some Member States.

The major environmental issues are as follows:

- The main source of atmospheric emissions relevant here arises from the production of virgin PVC (which is replaced by high quality recycling), followed by incineration (for which we have included the emissions associated with up- and down-stream activities, such as production of pollution control reagents). The emissions of air pollutants associated with recycling are, in contrast, small.
- As already noted, there is a high demand for alkaline reagents to abate emissions of hydrogen chloride at incineration.
- The presence of phthalates and other plasticisers, which can account for a large part of flexible PVC formulations, is also problematic. Incineration is effective in destroying them. However, the phthalates present in flexible PVC diverted to landfill would be expected to gradually leach out, generating problems for treatment of leachate.
- The converse seems true for heavy metals (cadmium, lead, etc.) present as stabilisers in PVC. These are likely to be more mobile in ash from an incinerator than in the original PVC matrix.

To the extent possible the external costs associated with each scenario have been calculated, and are summarised in the following table. Analysis is biased towards assessment of the effects of air pollution. Of these, effects mediated through climate change and impacts on health have the greatest effect on results. The uncertainties that affect this part of the analysis have been taken into account in establishing best estimates and upper and lower bounds. These account for alternative assumptions regarding, for example, global warming externalities, valuation of mortality linked to emissions of particles, SO_2, NO_x, and the inclusion or exclusion of chronic effects of PM_{10} (including secondary particles). In all cases the environmental consequences of diversion from incineration lead to environmental improvement across the range of effects for which quantification has been possible.

The environmental analysis shows that for 'best' and 'high' valuations of externalities, the environmental benefits are sufficient to outweigh the financial costs of scenario 1, even when the avoided 'incinerator subsidy' is excluded from the financial costs. However, for scenario 2, only when the 'high' valuation of externalities is adopted do the environmental benefits exceed the financial cost of the scenarios. Scenario 3 shows a net cost saving in both financial and environmental terms.

Present value environmental externalities for the EU-21 of diverting PVC (4% discount rate). Negative figures represent benefits. Since the differences between the 'high' and 'low' incineration futures were negligible, results for the scenarios are shown here as averages.

	Scenario 1	**Scenario 2**	**Scenario 3**
Waste diverted, million tonnes2000-2020	**4.5 to recycling**	**9.76 to recycling**	**9.6-11 from incineration to landfill**
Total costs, million €			
Low	-112	-184	-121
Best estimate	-847	-1389	-529
High	-3123	-5271	-2569
Annualised costs, million €/year			
Low	-8	-14	-9
Best estimate	-62	-102	-39
High	-230	-388	-189
Cost per tonne of waste diverted, € /tonne			
Low	-25	-19	-12
Best estimate	-188	-142	-51
High	-693	-540	-249

It is necessary to ask how the numerous externalities that are omitted from this analysis would affect the final result – would they promote the case of incineration or not? It looks likely that most would increase the benefits of the diversion of material from incineration. One exception relates to the fate of phthalate plasticisers which are destroyed by incineration. Landfilled PVC would form a reservoir of these chemicals that could slowly leach out over time. The consequences of this are then dependent on the efficiency of leachate collection and treatment, proximity to drinking water supplies, etc.

Overall, we conclude that it is likely that there will be benefits to be gained from diverting PVC away from incineration, particularly to recycling, though there are clearly very finite limits to what can be recycled. There are also economic limits for separation of PVC mingled with other types of waste. Whatever the future for PVC this problem will remain with us for many years as a consequence of the large stock of long-lived PVC products currently in use throughout Europe.

Contents

Appendices

1 Introduction

PVC (polyvinyl chloride) is an important polymer with many applications in industry, commerce and households. The basic building block of PVC, vinyl chloride monomer (VCM) was first synthesised by Regnault in 1835 and Baumann recorded its polymerisation, triggered by sunlight, in 1872. Patents for PVC manufacture were taken out in 1912, but pilot scale industrial manufacture did not begin until the early 1930s, in Germany and the United States. The raw materials for PVC production are hydrocarbons from oil or natural gas, and sodium chloride from salt deposits. The hydrocarbon feedstock is converted to ethene (ethylene) and the sodium chloride electrolysed to produce chlorine. The ethene and chlorine are then reacted through several stages to produce VCM, the overall process being represented by the following equation:

$$\underset{\text{ethene}}{2C_2H_4} + \underset{\text{chlorine}}{Cl_2} + \underset{\text{oxygen}}{1/2O_2} = \underset{\text{VCM}}{2C_2H_3Cl} + \underset{\text{water}}{H_2O}$$

PVC consumption in Western Europe in 1997 exceeded 5 million tonnes, accounting for 18 percent of total polymer production. PVC used for pipes and building profiles was among the top ten applications of plastics, accounting for almost 9% of plastic consumption[1]. PVC also finds major uses in vehicles, electrical and electronic equipment and packaging. PVC owes its versatility to the fact that the pure PVC polymer (i.e. PVC *resin*) can accept the addition of a wide range of additives that modify the properties of the resultant PVC *compound*. In this way, the mechanical properties of PVC compounds can be varied from rigid to flexible, whilst other additives are used to increase thermal stability, alter impact resistance, colour, transparency and texture, to mention but a few examples.

Several major applications of PVC are for products with long service life times. Cars, electrical, household and industrial good typically last for between 5 to 15 years before they are worn out or replaced, and the PVC that they contain, along with other components, becomes a waste management issue. For building products such as pipes and profiles[a] (the fastest growing application area for PVC), products may last for decades before needing replacement. As the widespread production of many of these long-lived products began only within the last two to three decades, society is already committed to dealing with increasing amounts of PVC wastes that will enter the waste management system over the coming decades. This commitment for managing PVC waste from long-lived products is effectively de-coupled from present-day production patterns. There will also be differences between Members States that reflect variations in product histories and applications.

At present, the vast majority of PVC-containing wastes within the EU are disposed of to landfill. PVC resin is essentially inert under landfill conditions (indeed, one of its applications is for drainage pipes used in landfills). However, certain additives may leach into landfill liquor and so could eventually pose a potential threat to human health and the environment. The evidence underpinning these concerns has

[a] Such as window and doorframes, fascias, cladding, cable ducts etc.

been examined in a parallel study for the European Commission[2] on the behaviour of PVC in landfills.

Most of the remaining PVC waste is co-incinerated with municipal solid waste (MSW) in large incinerators. Related concerns include the possible formation of traces of toxic chlorinated organic compounds, the impacts of PVC in the waste stream on the requirements for reagents to control emissions of hydrogen chloride (a major combustion product), and its impacts on other releases and discharges from incinerators. These issues have been examined in a further recent study for the European Commission[3]. Options for recycling PVC into other plastic goods (mechanical recycling) or as a source of hydrocarbon feedstock (feedstock, or chemical recycling) have also been the subject of recent major study contracts for the European Commission[4] [5].

The specific objective of this study is to *assess the economic implications of diverting PVC waste away from incineration*. The approach adopted evaluates three scenarios for reducing PVC incineration, to be achieved by 2020. The study identifies the major changes in financial costs for PVC waste management and environmental burdens associated with achieving the scenarios, taking account of the impacts of other policy measures adopted at EU or Member State level. The analysis examines the extent to which recycling can consume the PVC diverted from incineration and the wastes streams and PVC applications that will contribute most to achieving the targets and evaluates the costs of support measures to stimulate recycling. The approach entails constructing a forward view to 2020 of PVC waste disposal and recycling in the EU and developing an inventory of environmental burdens associated with achieving each of the diversion targets, compared with 'Business as Usual' (BAU). Where possible, environmental burdens have been quantified in monetary terms, to allow the economic and environmental costs and benefits to be compared on the same scale. The study encompasses the countries that make up the present EU15, plus a further six countries[b] that may accede to the Union within the next few years, together referred to here as 'EU-21'.

The analysis has been performed in the following stages:

- System characterisation (Section 2)
- Model development (Section 3)
- Scenario Analysis (Section 4)
- Financial analysis (Section 5)
- Environmental analysis (Section 6)
- Conclusions (Section 7)

Section 2 (system characterisation) establishes estimates of future PVC waste arisings in major applications across the EU-21 and assesses the impact of national and EU-wide waste management policy in determining the destination of PVC wastes. This stage of the analysis is used to build up a picture of PVC waste management under the BAU baseline future. Three alternative scenarios for diverted PVC waste away from incineration to recycling or landfill are then elaborated.

[b] The Commission has identified the following accession countries for inclusion in this analysis: Cyprus, Czech Republic, Estonia, Hungary, Poland and Slovenia.

Section 3 outlines the model developed to characterise the major sources of environmental burdens and credits associated with diverting waste from incineration. The system includes impacts associated with the replacement of PVC diverted from incineration by other wastes, and factors associated with the manufacture, transport and disposal of reagents used to control emissions from incinerators and burdens from manufacturing virgin compound avoided by recycling.

The scenario analysis is presented in Section 4. It characterises the environmental burdens and credits associated with incinerating, landfilling, recycling and manufacturing PVC, so providing the data underpinning the scenario analysis. The scenario analysis then presents the cumulative burdens associated with achieving the scenarios over the 2000-2020 time horizon of the study. The burdens are reported for representative formulations of rigid and flexible PVC, since there are important differences in their respective environmental burdens.

Having completed the analysis of burdens and credits, the next stage is to evaluate the financial costs of moving from BAU to each of the scenarios (Section 5) from a waste management perspective.

The analysis of the environmental externalities associated with each scenario and waste management option is presented in Section 6. The conclusions from the study are presented in the final section (Section 7). Supplementary information is provided in Appendices 1 to 9.

2 System characterisation

In this Section we build up information on the PVC waste management system that forms the basis of the scenarios of alternative waste management futures that are analysed in Section 4. We begin by outlining the properties and uses of PVC that determine the waste streams to which PVC reports and go on to outline recent estimates of future PVC waste arisings. This is followed by a review of waste management options for PVC, including the latest estimates of the potential for recycling. We conclude with a review of relevant national and EU-waste legislation, so building up the scenarios for subsequent analysis.

2.1 PVC COMPOSITION AND APPLICATIONS

The composition of waste materials plays a potentially major role in determining emissions and releases to the environment during their management and disposal, and in this respect PVC is no different from other wastes. PVC compound contains a range of additives, some of which may be available to leach from the polymer matrix in landfills. Other additives, such as heavy metals, may be converted to more mobile forms after incineration, whilst organic additives are generally destroyed during incineration. We therefore need to understand the basic ingredients and composition of typical PVC formulations in order to estimate environmental burdens for PVC waste management.

There are two basic types of PVC compound – flexible (or plasticised PVC, sometimes referred to a pPVC) and rigid (or unplasticised, uPVC). Flexible compounds typically contain 40 to 60 parts plasticiser added for every 100 parts PVC resin[c] to confer the required flexibility and elasticity to the product. Applications of flexible PVC include cable insulation, sheeting, soft furnishing, soft toys, hoses and blood bags. The most widely used plasticisers are alkyl esters of phthalic acid, such as di-(2-ethylhexyl phthalate) (or DEHP for short)[d] etc, sometimes mixed with chlorinated paraffin oil.

Both flexible and rigid PVC formulations require stabilisers to prevent heat and light-mediated changes in the molecular structure of the polymer chain, accompanied by release of hydrogen chloride, which would result in discoloration and embrittlement. Without the addition of stabilisers, PVC would deteriorate rapidly during extrusion/blending processes and in everyday use. The traditional stabilisers contain metal salts, particularly those of lead, zinc, tin calcium and barium, and to a lesser extent, cadmium. Examples of stabiliser systems include the sulphates, carbonates, stearates and laurates of the above metals. Lead-based stabilisers are the most widely used, accounting for about 70 per cent of sales in the EU in 1998[6].

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[c] The PVC industry usually expresses composition of compound in terms of the amount of each additive required per hundred parts of pure PVC resin. Whilst this terminology is useful for formulators, care must be taken to avoid confusion with the more generally used approach of expressing concentrations relative to the mass of the final mixture.

[d] More correctly known as *bis*-(2-ethylhexyl) phthalate.

Stabilisers are usually added at a rate of less than 1 to over 8 parts per hundred of resin, depending on application. Cable insulation, for example, may contain relatively high levels of lead stabiliser needed to confer maximum heat stability. There is a very wide range of stabiliser systems. Factors which drive the choice for a given application, apart for cost and heat stability of the finished product, include risks of toxicity (lead and cadmium are not used for food wrapping and medical products), transparency and appearance of the finished product and compatibility with other additives.

Other additives include inert fillers such as chalk, pigments and dyes, blowing agents[e] to give a foam texture (on wall paper, leatherette etc), lubricants to reduce frictional heating during extrusion and moulding, flame retardants, and other polymers added to improve impact resistance. Titow[7] provides an extensive range of examples of typical PVC formulations for a range of applications. This provides a good indication of the vast range of possible combinations of additives and hence gives an indication of the difficulty of defining a representative PVC formulation.

As a result of its versatility as a polymer, PVC finds application in a very wide range of products, and so occurs in a wide range of waste streams once these products have reached the end of their lives.

2.2 SOURCES OF PVC WASTE

There are two principal sources of PVC wastes: *pre-consumer* and *post-consumer* wastes. Pre-consumer wastes consist of both production and installation wastes. Production waste comprises compound left over from the manufacture of PVC products, such as batch remainders from extrusion mouldings and various trimmings and off-cuts from sheet and profile manufacture. This material is available in a clean condition at the point of production and consequently most is recycled internally within the manufactory process and so never enters the external waste stream. Additional pre-consumer waste comes from trimmings left over from, for example, flooring and replacement window installation and replacement pipework (installation wastes). Pre-consumer wastes account for about 12 per cent of PVC waste arisings at present and around 85 per cent of this, (some 420 ktonnes/year in the EU-15) are currently recycled[4]. Relatively little PVC of pre-consumer origin enters the waste stream and therefore these wastes have been excluded from the present study.

The predominant source of PVC waste (about 88 per cent) is of post-consumer origin and this waste forms the subject of the present study. Post-consumer wastes consist of products that have been discarded at the end of their useful lives. As a result, post-consumer wastes tend to be dispersed in low abundance over a large number of users and typically require extensive cleaning to remove contaminants before they can be used for recycling. The expense of collection, sorting and processing combine to make recycling costs much higher than the mainstream options of landfilling and incineration, and so only a tiny fraction (about 3%) of post-consumer PVC waste is currently recycled[4]. Some post-consumer wastes may

[e] Blowing agents are used to generate nitrogen bubbles in the finished compound to produce a foam effect. The blowing agents themselves decompose and so do not persist into the finished products.

in fact never be recovered. An example of non-recovery would be PVC water pipes that remain in the ground after replacement.

Predictions of future PVC waste arisings are subject to considerable uncertainty. Estimates are based on the amount of each product type that is likely to be recovered (i.e. 'available' waste), which is in turn based on the history of consumption (production, imports and exports) and the estimated lifetime of the products. For some products with a relatively short life (such as packaging waste) most of the PVC consumed enters the waste stream within one year of production, so waste production is closely coupled to consumption pattern. But for other products with much longer lives, the link between consumption pattern and waste production is much less certain. This is reflected by the ratio of waste generated to consumption in a given year. For short lived applications such as packaging and household waste, the ratio is over 80 per cent, but decreases to below 40 per cent for electrical and electronic good and automotive components, to only 18 per cent for building applications[1]. The range of uncertainty in the overall quantities of PVC waste arisings as a result of these factors has been estimated to be +/- 15 per cent[4].

Detailed information on PVC waste arisings for a range of applications for western European countries was made available to us by EuPC (European Plastic Converters)[f]. The waste predictions were based on a detailed model developed whilst this study was in progress, drawing on industry information on consumption patterns and product life. EuPC data were used in this study and in the recent assessment of mechanical recycling of PVC[4] led by Prognos. There is a difference, however, in the definition of the term 'available' waste used by Prognos and EuPC. The latter refer to available waste as the amount theoretically available for mechanical recycling, whereas Prognos define available waste as the amount that ends up in the waste stream – i.e. is available for landfilling, incineration and recycling. We have adopted the Prognos definition of available waste and have therefore converted EuPC's waste data to bring the estimates into line with those used in the Prognos study. This definition excludes non-recovered wastes such as pipes and cables that may remain in the ground after use. Prognos assume that 30 per cent of pipes and cables for underground application are available and that for all other waste products the availability is 100 per cent.

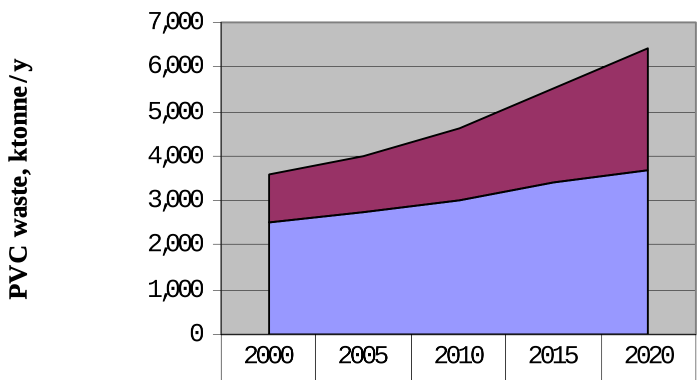
EuPC could not provide estimates of waste production in the six accession countries included in this study and we were unable to track down any information on this from industry or government bodies in the countries concerned. We have therefore estimated accession country waste arisings from the relationship with gross domestic product shown by the other countries included in the study[g]. Predicted arisings of post-consumer PVC waste for the EU-21 are shown in Figure 1. Total post-

[f] The EuPC modelling of PVC waste arisings evolved during the course of this study. Data on waste arisings was initially supplied to us for sixteen generic product types (eg sheets, films, coatings etc) for eighteen Western European countries. EuPC subsequently provided a more detailed breakdown by product type (63 categories in total) with total arisings for Western Europe, but without a country-by-country breakdown. Our estimates of country arisings for the EU-15 is therefore based on the recent, more detailed product data, proportioned according to EuPC's initial country estimates.

[g] Waste arisings data from EuPC for the EU15 were highly correlated with Gross Domestic Product. The equation $y=ax^b$ (where y is PVC waste arisings in tonnes, x is GDP in billion € and a and b are regression coefficients) gave a line of best fit with a=119 and b=1.1643. The relationship showed that GDP could account for over 97% of the variation in waste arisings.

consumer PVC waste across the whole EU-21 is predicted to increase from about 3.6 to 6.4 million tonnes/year between 2000 and 2020. Flexible products make up the bulk of this waste in 2000, accounting for 70% of waste arisings, but by 2020, the more rapid growth in waste derived from rigid formulations will have increased and flexible products will have fallen to about 58%. These trends need to be taken into account in the analysis since they affect the burdens from PVC waste management.

Figure 1: Available post-consumer PVC waste, EU-21



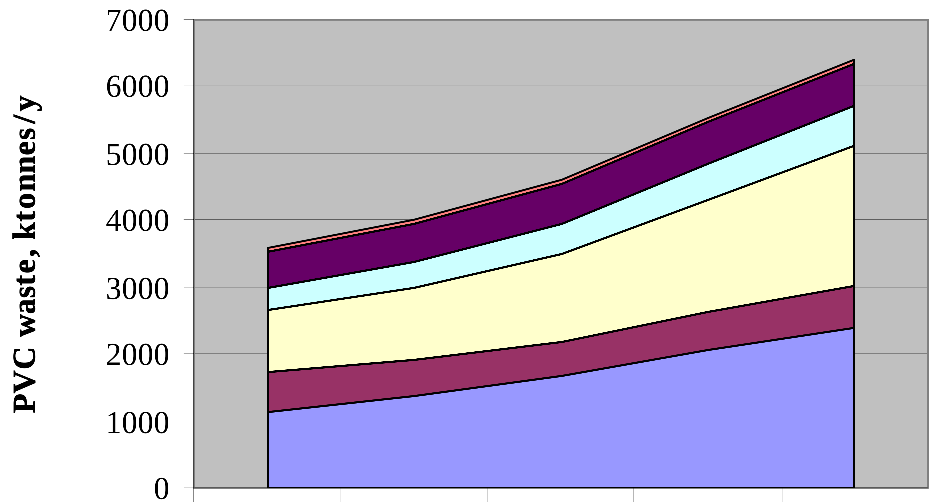
	2000	2005	2010	2015	2020
Total rigid	1,076	1,255	1,584	2,108	2,717
Total flexible	2,505	2,751	3,016	3,418	3,691

The application to which PVC is put determines the waste stream to which it will eventually report and hence the waste management options most likely to be followed. EuPC provided data on some 63 individual and generic product types that make up post-consumer PVC waste. These products are listed in the first part of Appendix 1 ('EuPC Product categories'). To make the analysis more manageable, we have grouped these products into six application areas (construction, packaging, household and commercial, electrical and electronic, automotive and 'other' – a small category made up of waste from agriculture and medical applications). The major product types given by EuPC within these application have been retained, whilst some minor applications have been grouped according to whether they are composed of rigid or flexible PVC. The categorisation is broadly similar to that employed in the mechanical recycling study[4], although one difference is that we have combined the 'furniture' application in that study within our household and commercial waste application area. A total of 28 categories of PVC waste were used in the present study. These are identified in the second table in Appendix 1 ('AEA product categories').

Even with this grouping, only three of the 28 product categories account for more than ten per cent of total arisings, as indicated in Appendix 1. These are flexible products in automotive (14 per cent of total in 2000), household and commercial (17 per cent) and construction (14 per cent). This illustrates the wide diversity of PVC applications and uses.

The dominant role of the construction ('Constr') and household and commercial ('H&C') applications as major contributors to post-consumer PVC waste is clear from Figure 2. Further details of the composition of construction, packaging and household and commercial waste, are shown in Figure 3, for 2000 and 2020. Rigid construction products (windows and other profiles, pipes etc) will increase almost fourfold over the next two decades, with a smaller increase in flexible construction products. Household and commercial applications will also show significant growth in the next twenty years. Rigid packaging products on the other hand (such as bottles for mineral water etc) will increase slightly, with a change in the distribution among applications, mainly as a result of substitution of PVC for bottles by other polymers, principally PET. Arisings of flexible PVC waste in the automotive sector is predicted to show a small increase. The category labelled ‘other’ includes medical and agricultural uses, such as blood bags and horticultural films and is expected to remain static. Further details of waste arisings for all the application categories are shown in Appendix 1.

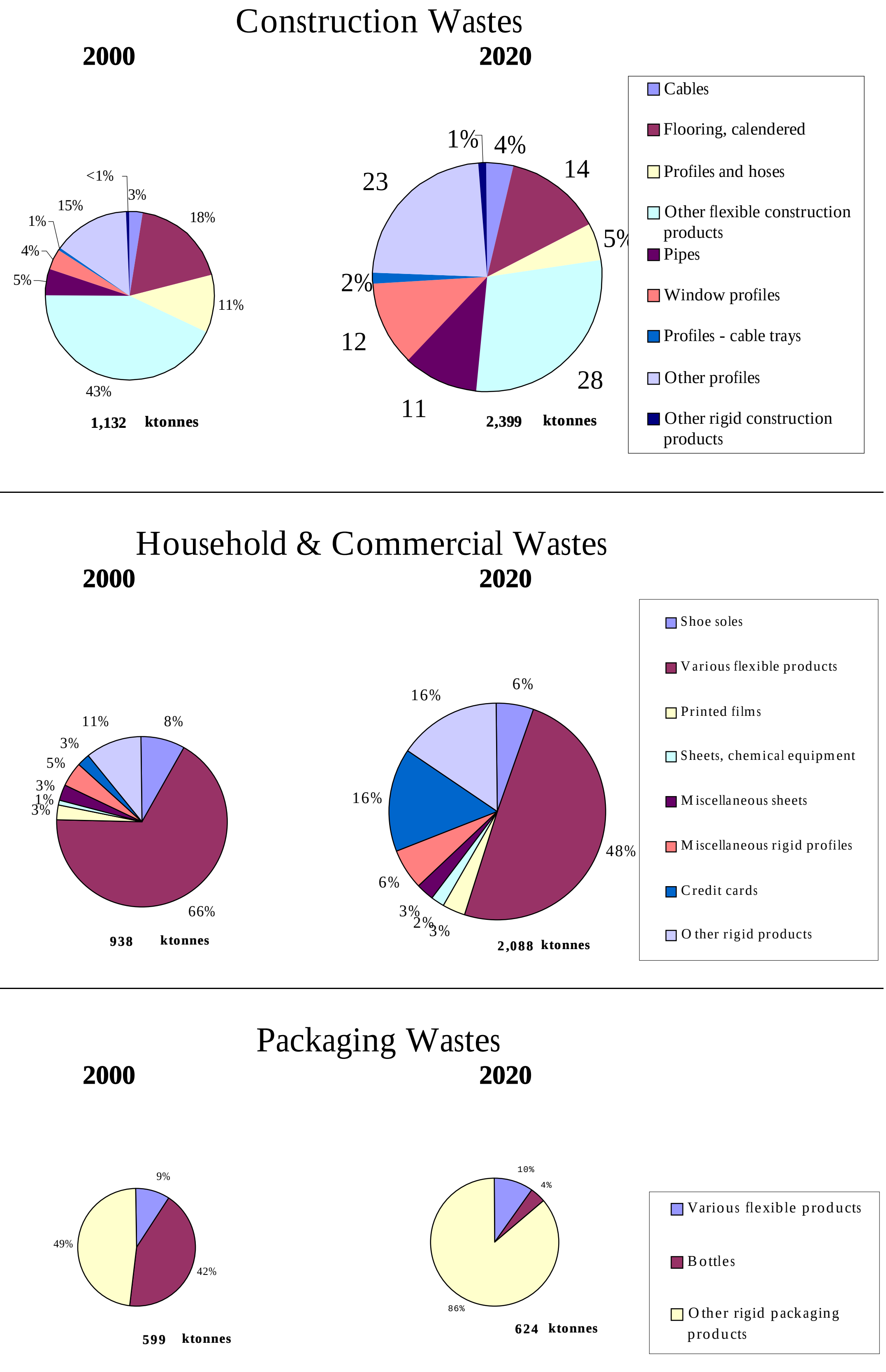
Figure 2: Post-consumer PVC waste composition.



	2000	2005	2010	2015	2020
Other	60	60	60	62	62
Auto	528	562	580	627	645
E&E	323	384	452	537	589
H&C	938	1097	1314	1670	2088
Packag	599	525	519	569	624
Constr	1132	1377	1676	2061	2399

Figure 3: Selected PVC waste stream composition 2000 and 2020.

(Pie sizes are indicative of total arisings and are not drawn to scale.)



2.3 IMPACT OF WASTE MANAGEMENT POLICY ON PVC WASTE DESTINATIONS

Despite the policy preference accorded to re-use and recycling, landfilling is still the most important disposal route for municipal solid waste in the EU, accounting for over 80% of non-recycled material, with most of the remaining waste going to incineration, mostly with energy recovery. Municipal solid waste is usually taken to comprise wastes collected from household as well as similar wastes collected from commercial and industrial operations, but definitions vary between Member States, so making rigorous comparisons difficult. PVC products discarded into the household and commercial waste stream are most likely to follow the same disposal route as MSW and so show a similar split between landfill and incineration. PVC wastes that are not collected with MSW will follow the disposal route characteristic of the waste in question. For example, at present almost all non-masonry construction waste is landfilled[8], along with PVC that forms part of the autoshred residues from vehicle recycling and plastics recovered from dismantling of waste electrical and electronic equipment. Recycling of PVC is considerably more expensive to the waste producer than either landfill or incineration and consequently recycling rates are currently very low. The disposal fee for PVC incinerated with MSW does not, however, reflect the full cost of incineration since the charges for the much larger quantities of reagents for controlling emissions of acid gases and residues needing disposal, compared with MSW, are in effect paid by all users of the incinerator. This issue is further elaborated in Section 5.

Landfill has traditionally been the least cost waste disposal option, but costs are rising with the requirement for sites to have greater levels of environmental protection. Large landfills today require extensive liners to prevent liquors (leachate) from polluting surrounding land or water resources and to collect methane, a potent greenhouse gas formed from the decomposition of biodegradable wastes.

Incineration developed in the 19th century as a means of reducing the bulk of waste requiring ultimate disposal, producing in the process a less hazardous inorganic ash residue for disposal. By the early 1900s, incineration was exploited as a means of recovering energy (as heat and or electricity). Some 76 waste incinerators generating electricity were in operation in England alone by 1912. The original objectives of incineration as a pre-treatment option for waste disposal, namely waste stabilisation and bulk reduction, with energy recovery where appropriate, remain the prime objectives today.

Investment and operating costs of modern incinerators are significant, but economies of scale apply, with modern MSW incinerators having a capacity typically in the range 200 to 1,000 ktonnes/year. Incineration is therefore deployed in large conurbations producing sufficient waste to make it cost-effective. The high costs for incineration are partly offset by sales of energy, recovered as heat and/or electricity, and the sale of recycled material, such as some grate ash and ferrous metal recovered from the combustion process. Smaller incinerators (25 to 100 ktonnes/year) have also been widely deployed for treating the wastes of smaller, isolated communities in some Members States, for example, France, but most of these small incinerators do not recover energy. New EU-wide emission standards for incinerators are due to be introduced in 2005 under the proposed Directive on the Incineration of Hazardous and Non-hazardous Waste, that will further strengthen the current limits applied under the 1989 Incineration Directives (89/369/EEC and 89/429/EEC). As a result, nearly all of these small, old incinerators are expected to cease operation within the next 5 years, it being uneconomic to upgrade them to comply with the new emission limits. In addition, the new regulations will require that incinerators recover energy wherever feasible.

PVC combustion also takes place in smaller scale incinerators for clinical and other hazardous waste and plastic wastes are also used as a substitute fuel in some cement kilns. These routes are therefore also potentially open to PVC that occurs in the relevant waste streams. However, recent estimates indicate that the amount of PVC accepted by these alternatives is very small. This is because of the relatively low concentration and low absolute amount of PVC in hazardous and clinical wastes. In addition, cement kilns are limited in the amount of chlorine that can be accepted in the waste stream. MSW incinerators therefore remain the principal routes for PVC incineration[3]. We have therefore focussed in this study on such plant.

Incineration with energy recovery, and recycling, are expected to increase significantly across the EU over the next two decades. The Landfill Directive imposes targets for reducing the amount of biodegradable and certain other wastes that can be disposed of in landfills. Whilst much of the diverted wastes will be dealt with through increased use of recycling (including composting and anaerobic digestion), energy recovery through incineration offers the only established means of recovering value for those wastes for which material recycling may not be technically or economically feasible.

Some Member States, mostly those that already have significant incineration capacity, have announced national policies for banning the landfilling of raw (i.e.- untreated) organic wastes, including non-biodegradable materials such as plastic. For these countries, we expect to see a significant growth in PVC incineration across all waste streams, since the alternative option of landfill disposal will become increasingly constrained and the preferred alternative of recycling has limited technical and economic feasibility. Table 1 lists countries in the EU-21 that have, or propose, legislation that is likely to reduce landfilling plastic waste.

It must be noted, however, that considerable variation exists between Member States according to how far advanced their proposed measures are and the extent to which they will affect plastic waste landfilling in general and PVC waste in particular. Some countries, notably Germany, Austria, the Netherlands and Denmark are well advanced in this respect and landfilling of plastic waste streams is likely to be substantially reduced within the next five years. However, in the case of Denmark, there is a preference for landfilling over incineration for non-recyclable PVC wastes. The situation in France, which proposes to require that only ‘final’ waste can be landfilled after 2002, is still under review. In conclusion, the impact of some national landfill policies on future landfilling of PVC waste streams is still uncertain. It varies markedly between countries in terms of level of advancement and types of waste that may be landfilled, and, taking this group of countries as a whole, is unlikely to result in a complete shift from landfilling of PVC, at least within the coming decade. The impacts of these considerations will be incorporated into the analysis scenarios, described below.

Table 1: Member State policies on landfilling

Country	Remarks
Germany	Since 1/1/99, only 'final' wastes can be landfilled. It is proposed to ban the landfilling of carbonaceous wastes by 2005.
France	As of 1/7/2002, only 'final' waste can be landfilled.
Belgium	As of 1/7/2000, only pre-treated inert waste can be landfilled (Flanders only).
Denmark	Since 30/4/97, only pre-treated waste can be landfilled. However the PVC strategy adopted in 1999 aims to keep PVC waste out of incinerators where possible.
The Netherlands	Landfilling of plastic wastes is banned.
Sweden	Carbonaceous wastes to be banned from landfills from 2001.
Austria	Carbonaceous wastes to be banned from landfill from 2004.

For other Member States, where no further restrictions on landfilling beyond those required under the Landfill Directive are proposed, PVC wastes will continue to go to landfill disposal, unless subject to additional recovery targets related to specific waste streams. Wastes where specific recovery targets apply are packaging, electrical and electronic wastes and automotive wastes. Household and commercial wastes will follow the MSW waste stream.

To assist in the estimation of future incineration rates across the EU-21, we have divided countries according to whether there is likely to be a significant move away from the landfilling of PVC wastes and a concomitant growth in incineration to dispose of non-recycled waste. The two groups are referred to as 'Landfill Directive Plus' and 'Landfill Directive Only' countries. They are listed in Table 2, which also shows shares of PVC waste arisings, using data provided by EuPC for Western Europe and by extrapolation from gross domestic product for the accession countries. A similar distribution is seen for 2020 (results not shown). Landfill Directive Plus countries will account for 53 per cent of arisings in 2000, with Germany and France together making up 44 per cent of the total. In the Landfill Directive Only countries, the main contributors are Italy, UK and Spain (together adding a further 37 per cent). Given the small contribution of the accession countries to total PVC waste arisings in the EU-21 (less than five per cent), errors introduced from the method of estimation from GDP are unlikely to be significant.

Table 2: Proportion of PVC waste arisings within EU-21

Group	Member State	Share of EU-21 post consumer PVC waste
'Landfill Directive Plus'		
	Germany	25.1%
	France	18.4%
	Belgium & Luxembourg	3.4%
	Netherlands	2.9%
	Sweden	1.9%
	Austria	1.4%
'Landfill Directive Only'		
	UK	14.9%
	Italy	14.7%
	Spain	7.4%
	Portugal	1.8%
	Greece	1.2%
	Finland	1.0%
	Denmark	0.7%
	Ireland	0.5%
Accession countries		
	Poland	2.9%
	Czech Republic	1.0%
	Hungary	0.6%
	Slovenia	0.1%
	Cyprus	0.1%
	Estonia	0.1%

In addition to the Landfill Directive, there are further EU-wide measures in effect or proposed that will affect the options for managing specific waste streams that contain PVC. These concern packaging wastes, electrical and electronic wastes, end-of life vehicles and construction waste. These measures and their possible impacts are described below.

2.3.1 Packaging wastes

Table 3 shows the estimated composition of packaging wastes in Western Europe, according to APME[1] (Association of Plastics Manufacturers in Europe). Plastic make up about 11 million tonnes out of 66 million tonnes of packaging waste, of which PVC accounts for 0.7 million tonnes.

The Packaging and Packaging Wastes Directive (94/62/EC) requires that by no later than 2001, between 50 and 65 per cent (by weight) of packaging must be recovered. Within this general target, between 25 and 45 per cent will be recycled, with a minimum of 15 per cent for each packaging material. The implications for PVC packaging wastes are the same as for other plastic packaging wastes – i.e. higher and higher rates of recovery and recycling and lower rates of landfill. Those Member States that go beyond the Landfill Directive will opt for incineration with energy recovery, rather than landfill, for the remaining unrecovered plastic.

Table 3: Packaging waste arisings and composition in 1997 (APME[1]).

Source of waste	Quantity
Total Packaging Waste arisings	66 million tonnes
Glass	21%
Others – including wood	16%
Paper and cardboard	38%
Metal	8%
Plastics	17%, 11 million tonnes
of which PVC accounts for	~7%, 0.7 million tonnes

2.3.2 Electrical and electronic wastes

PVC, together with a wide range of other plastics, finds extensive use in thermoformed sheets and moulded products in a wide range of electrical and electronic appliances, and in cable insulation. The current (3rd) draft of the proposed Waste Electrical and Electronic Equipment (WEEE) Directive proposes recycling rates of the collected WEEE ranging from 70 to 90%, depending on nature of the appliances. The mixed plastic waste of which PVC forms a minor part originates from the mechanical processing of WEEE. This can be recycled to low quality application, but most is simply landfilled or sent for incineration (with energy recovery). Although WEEE generally has a relatively low content of plastic and so makes a small contribution to overall recycling rates in this sector, market pressure and competition between materials may nevertheless force greater recycling of plastics in the future.

2.3.3 Automotive waste

PVC, along with other plastics, finds extensive use in cars and trucks in fuel tanks, bumpers, dashboards, interior linings, seats and batteries. Typically a car weighing about 1 tonne would contain about 93 kg of plastic components[9], although this proportion is set to increase with greater drives for lightweighting needed to achieve higher fuel efficiency. Although many of these plastic components are composites, about 10kg of PVC material / componentry is typically present.

Currently, cars are disposed of through fragmentisers to recover ferrous and non-ferrous metals. Plastics end up in the ‘fluff’ fraction (sometimes called ASR – automotive shredder residue) as a mixture with everything that isn’t metal. The proposed End of Life Vehicles Directive may introduce recovery targets for vehicles of 85% in 2005 and 95% by 2015, with recycling rates for the recovered vehicles of 80 and 85% respectively. Recycling rates up to about 75% could be met by metals alone, but achievement of the higher rates envisaged under the Directive may require the industry to pursue plastics as well.

Currently, about 76 per cent of automotive plastic waste is landfilled in Western Europe and a further 15 per cent is incinerated with energy recovery. The remainder (mostly polypropylene bumpers and batteries) is mechanically recycled. There is very limited potential for mechanical recycling of PVC from automotive waste, as discussed later, although we understand that one such scheme (‘Autovinyl’) is in operation in France.

2.3.4 Construction wastes

Plastics make up about 0.2 per cent of construction and demolition waste[1]. However much of it is in the form of large single polymer items (such as pipes, cables, windows and other profiles) that need to be separated from mineral wastes (concrete and masonry) before the latter is suitable for crushing and recycling into secondary aggregates[8]. Some countries already have measures in place to reduce the landfilling of construction wastes, for example, Sweden intends to reduce landfilling of such material by 50 per cent in 2000. The Netherlands have already achieved recovery rates of 80-90 per cent by banning the landfill of construction wastes and in Germany selective collection and recycling of such wastes is undertaken by some municipalities.

Whilst much of the current emphasis in construction waste management policy is on reducing the use of primary aggregates through recycling, the need to separate plastics (and wood, metal etc) will make recycling of the plastic component more attractive. It will also increase the potential for residual separated non-mineral wastes to be diverted to incineration, rather than landfill, so resulting in a potential increase in PVC incineration, particularly in the Landfill Directive Plus countries.

2.4 PVC RECYCLING

In addition to the currently dominant waste management options of landfill and incineration, some PVC wastes can also be recycled by *mechanical* or *feedstock* processes. In mechanical recycling, the PVC products are collected, sorted and processed to produce a recyclate that can substitute for virgin PVC compound of a similar composition and thus be recycled into similar products, sometimes defined as 'high quality recycling'. High quality recycling requires good quality recyclate with a very low degree of contamination. Mechanical recycling is also possible for contaminated PVC, usually mixed with other plastics and materials from which further separation is either not technically feasible or too costly – eg from coated fabrics etc. Such recycling into substitutes for non-PVC materials is often known as downcycling. Examples include plastic fencing, traffic cones, plant pots and industrial flooring. Opportunities for using PVC with other polymers are, however, constrained by the need to keep processing temperatures below 210 °C to prevent PVC decomposing[4]. This temperature is too low to allow mixed recycling with other plastics such as polypropylene, polyamide, polycarbonate and polyethyleneterephthalate, although it is acceptable for some polyethylene and polystyrene.

An alternative to low quality mechanical recycling of mixed plastic wastes is *feedstock* recycling. Feedstock recycling involves the thermal disruption of polymers to produce a hydrocarbon feedstock for the petrochemical industry or direct use of plastic waste as a reducing agent in blast furnaces. In the case of PVC, this also releases the chlorine, in the form of hydrogen chloride. According to the technology employed, current feedstock recycling facilities can accept a chlorine content in the feedstock of maximum 10%[10].

The vinyl industry has recently completed a review of technologies for feedstock recycling of high PVC waste . Following the review, plans were announced in 1999 to build a 1000 to 2000 tonnes/year demonstration plant that will operate on high PVC waste and recover hydrogen chloride, with the possibility of a full scale plant (25000 tonnes/y) by 2005. Recovery rates for chlorine (as hydrogen chloride) are expected to be around 90-94%. Disposal fees for treating the waste delivered to the plant (i.e. exclusive of collection, sorting and transport) will be between € 200 – 300 /tonne, inclusive of credits for the recovered hydrocarbons and hydrogen chloride. Overall costs for feedstock recycling is therefore likely to be around twice the gate fee[h], using average reported estimates for collection and sorting[i].

More recent developments on feedstock recycling of high chlorine waste, with recovery of hydrogen chloride, have been reviewed by the parallel study undertaken for the European Commission by TNO[5]. The study differentiates between technologies for treating mixed plastic waste and those specifically for dealing with PVC-rich waste streams with their higher chlorine content. Feedstock recycling of mixed plastics waste with low chlorine content has only been realised in practice in Germany, where 360,000 tonnes were treated in 1998. Assuming a PVC content of 3 to 7.8% this would include the treatment of 10,800 and 28,000 tonnes of PVC respectively. Of the three purpose built feedstock recyling plants, two have in the meantime been shut down. Four processes aimed at treating chlorine-rich waste were described, all of which aim to recover chlorine as hydrogen chloride or salt solution. One incineration-based technology is currently operational with a capacity of 15,000 tonnes PVC per year. Gate fees for the processes studied ranged from € 100 to 350 /tonne. The study concludes, however, that chemical recycling of PVC-rich waste is in financial terms no real alternative to mechanical recycling for those wastes where the latter has proved to be technically-feasible, with the possible exception of flooring. Chemical recycling is therefore most likely to focus on those wastes for which mechanical recycling is not feasible.

Given the current limited state of commercial development of feedstock recycling, this study has focussed mainly on mechanical options for recycling.

2.4.1 Economics of mechanical recycling of PVC

Opportunities for recycling PVC are subject to the interplay of market forces which ultimately dictate whether, in a free market system, recycling can be done profitably on a commercial basis, or whether additional economic or regulatory support in the form of incentives are required to establish a viable system.

The principal stages in PVC recycling are similar to those involved in any material recycling operation, and can be summarised as follows:

Mobilisation	**Processing**	**Sale / credit**
Collection→ Sorting→	Dismantling→Cleaning→ Shredding/extrusion→	Recyclate sale
	Or thermal processing to feedstock / chemical recycling	*Credits for recycled feedstock*

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[h] The ‘gate’ fee is the amount charged at the feedstock recycler’s gate for waste to be disposed of through the facility. The costs of collection, sorting and delivery etc (mobilisation costs) would thus be borne by whoever owns the waste.

[i] RECOUP estimates collection charges for mixed plastic waste at € 30-225 /tonne, whilst the AEA Technology report on Opportunities and barrier to Plastic Recycling (August 1996) estimate sorting costs at € 45-95 /tonne and baling and transport costs at € 15-90 /tonne. A sum of the mid-range values of these cost elements suggests a value of about € 250 /tonne for mobilising the waste to the feedstock recycling facility.

It is first necessary to mobilise the recyclable fraction before subsequent processing to produce a saleable recyclate. The overall economics of the process is given by the following equation:

Net cost of recycling = Gross costs of recycling – Income from sale of recyclate

Where

Gross costs of recycling = Mobilisation costs + Processing costs

Mobilisation costs are lowest where the largest quantities of recyclable materials is available in the highest concentrations, so helping to reduce transport and sorting costs. Processing costs can be minimised where products are easy to dismantle, contain a high proportion of the material to be recovered and are available with minimal contamination, so reducing the need for costly washing and cleaning procedures. For the recycling process to be commercially profitable, the total costs must be less than the sales value (or credits) from the sale of recyclate. The price of recycled PVC is at best about 70% of virgin compound. The latter is subject to considerable volatility, being closely dependent on oil prices and this volatility can act as a significant deterrent to the development of recycling capacity. For example, between 1989 and 1997, virgin PVC prices varied between 90 and 140 per cent of base year (1991) average[4]. Prices ranged from € 560 to 680 /tonne for the early part of 1999, but have since increased dramatically, finishing the year at € 740 to 850 /tonne.

Pre-consumer wastes are generally available at high concentrations in a clean condition, but even so, even pre-consumer PVC waste recycling is not always profitable. Highest recycling rates are achieved for those product groups where production wastes make up the bulk of pre-consumer wastes, such as shoe soles, bottles and injection moulded components, where recycling rates over 70 per cent may be achieved. Less than 70 per cent recycling rates are typical where installation wastes dominate the pre-consumer waste arisings, such as with composite materials and building products[4]. The latest estimate of total cost of recycling pre-consumer wastes is € 370-650 /tonne, or about € 100 / tonne less if the recyclate is simply ground up rather than being extruded. This compares with recyclate prices in the range € 200-450 /tonne, with the price commanded being strongly linked to quality[4] – hence pre-consumer wastes tend to generate the highest quality and so highest priced recyclate. Recycling rates are likely to pick up if the currently high price of virgin resin is maintained.

Similar considerations apply to post-consumer wastes, where the mobilisation and processing costs are even higher than for pre-consumer wastes and as a result recycling rates are very low. One exception, however, is in cable insulation recycling, but the economics of this are driven by the high value of the recovered copper or aluminium conductor. Having processed the cable to recover the metal, further processing of the insulation into a mixed plastic waste fraction for recycling can be done at break-even costs. Some 38 ktonnes of PVC from cables was recycled in the EU-15 in 1997/98, about 40% of total recycled PVC (excluding feedstock recycling)[4]. However, the future of PVC cable insulation recycling may be restricted by concerns over the amount of toxic polychlorinated biphenyls (PCBs) previously used as additives and the uncontrolled transfer of lead (added as stabiliser) to products made of the recyclate.

Other examples of post-consumer PVC waste recycling include bottles, other packaging, flooring, roofing, pipes, windows and other profiles[4]. The total present day rate of recycling is about 3%. Apart from cables, a considerable part of packaging wastes is recycled (about 35 ktonnes, including bottles). High-quality mechanical recycling operates for a few single product groups (such as window frames and pipes), but only to a very limited extent. This is partly because of the relatively small quantities of these long-lived products that are currently coming through the waste management system. There is therefore a very limited body of evidence on which to base estimates of future recycling costs.

Nevertheless, the latest study on PVC recycling[4] was able to estimate the likely technical potential for recycling various product groups via high and low quality mechanical recycling. These estimates were based, of necessity, on 'best guesses', which were cross checked in discussions between the study team and ECVM, EuPC and with related previous studies[11] [12] [13]. The potential recycling rates were estimated from the collection rates (i.e. the proportion of a given product group that can be separated from the mixed waste stream by separate collection) and the percentage in the separately collected waste that can be separated into a pure PVC fraction suitable for recycling. Further details are provided in the report. The results so produced, which are used to generate estimates of recycling rates and costs for the present study, are shown in Table 4. The cost estimates include capital costs (depreciation and interest) and an element of profit, but further breakdown is not possible from the information available.

Table 4: Mechanical recycling potential and costs for post-consumer PVC wastes.

(Data from Prognos (reference 4) unless stated otherwise)

PVC application / product group	Potential recycling rate,	High (H)/Low (L) quality Recycling	Mobilisation costs (A)	Processing costs (B)	Gross costs of recycling (C) = A+B	Sales proceeds from recyclate, (D)	Net cost of recycling, gate fee (E) = C-D
	*per cent**				*Costs in € /tonne*		
Construction							
Cables	70-90 (80)	L	N/A	N/A	N/A	N/A	-50-0
Flooring - calandered (F)	20-30 (25)	H	100-150	300-350	400-500	100-150	300-400
Profiles & hoses (F)	15-25 (20)	H	N/A	N/A	N/A	N/A	N/A
Pipes (R)	60-70 (65)	H	~120	~440	~560	~300	~250
Windows & profiles (R)	50-60 (55)	H	60-80 (a)	350-400(a)	~400-500(a)	~200(a)	200-300(a)
Profiles – cable trays (R)	30-50 (40)	H	N/A	N/A	N/A	N/A	200-300
Other profiles (R)	30-50 (40)	H	N/A	N/A	N/A	N/A	200-300
Packaging							
Bottles (b)	35-45 (40)	H	1110	340	1450	440	1010
Rigid films	15-25 (20)	L	N/A	N/A	N/A	N/A	700-1000(c)
Household & commercial							
Furniture	-	-				}	
Shoe soles (F)	15-25 (20)	H	}	}	}	}	}
Miscellaneous (F)	5-15 (10)	H	}	}	}	}N/A	}
Printing films (R)	30-40 (35)	H	}N/A	}N/A	}N/A	}	}N/A
Sheets, chemical equipment (R) **	30-40 (35)	H	}	}	}	}	}
Misc. sheet products (R)	20-40 (30)	H	}	}	}	}	}
Misc. rigid profiles (R)	10-20 (15)	H	}	}	}	}	}
Other rigid products (R) **	10-20 (15)	H	}	}	}		}
Electric & electronic							
Cables (F)	30-50 (40)	L	}	}	}	}	}
Adhesive tapes (F)	30-50 (40)	L	} N/A	} N/A	} N/A	}N/A	} N/A
Injection mouldings (F)	30-50 (40)	L	}	}	}	}	}
Automotive	-	-					
Other	-	-					

F= flexible, R= rigid PVC formulation. N/A data not available. * The ranges shown represent the estimated range of recycling potential for available post-consumer PVC waste calculated by Prognos. The numbers in parentheses are the 'chosen' estimates of potential recycling rates used by Prognos to generate their forward views of PVC recycling. The amount of PVC recycled in each category is estimated multiplying the waste arisings by the potential recycling rate. However, the categories indicated by ** above include other products that the Prognos study classified as not recyclable. The potential recycling rates for these product groups must therefore be corrected for the non-recyclable component. These correction factors are given in Appendix 1, under 'AEA product categories'. (a) Windows contain about 40 per cent PVC, the rest being mostly glass and metals, which are also recovered for recycling. Following discussions with Prognos, we have estimated costs for PVC recycling on the basis that all recovered materials are allocated the same cost. (b) Data for bottles provided from TN Sofres[14], rounded to nearest € 10. Processing costs include overhead, R&D and communication. Costs shown per tonne of bottles, except sales revenue, which is per tonne of PVC. (c) Based on costs for plastic waste recycling in Austria and Germany

The net cost to the waste producer of recycling post-consumer PVC waste (i.e. gross cost *less* income from sales of the recyclate) is generally greater than the cost of simply disposing of it, which explains why recycling rates are currently very low. The cost estimates for recycling in Table 4 are higher than landfill disposal fees (currently in the range € 20 to 150 /tonne) and incineration (€ 50-200 /tonne). The exception is low quality recycling of cable insulation that is driven by the high value of the recovered metal conductor, mainly copper and aluminium. Therefore, with this exception, recycling of post-consumer PVC waste is not generally profitable at present.

The costs of disposal options relative to recycling therefore exert a major influence on the extent of PVC recycling. Highest waste disposal costs are associated with high environmental standards, but are also affected by other factors such as degree of private/public sector involvement and commitment to high technical standards beyond those necessary to ensure regulatory compliance. For facilities of equivalent high standards, costs tend to be highest in Germany, the Netherlands and Scandinavian countries and somewhat lower for the remaining EU-15. The cost differential between disposal and recycling tends to be lower in these high cost countries and as a result higher levels of recycling are achieved. In contrast, some countries are still in the process of phasing out unmanaged dumping of wastes (such as Spain, Greece, Portugal and the accession countries) and so waste disposal is still available at very low cost, so increasing the competitive disadvantage of recycling. However, costs for waste management will increase markedly in these countries with the introduction of higher standards, at the same time improving the competitive position for recycling.

How much post-consumer waste could be mechanically recycled under the most favourable circumstances in the future? The Prognos study estimated the total theoretical potential for mechanical recycling of post consumer PVC waste of 1.2 million tonnes in 2020, or about 19 per cent of arisings. The prediction was derived from the estimates of available waste arisings in the relevant categories and the 'chosen' potential recycling rates given in parentheses in the second column of Table 4. This overall recycling potential sets an upper limit on the extent to which PVC wastes diverted from incineration can be taken up by recycling. This issue is further elaborated in the scenario analysis (Section 3.2).

2.5 PVC WASTE MANAGEMENT SCENARIOS

Taking account of the various economic and regulatory drivers outlined above, the next step in the analysis is to develop Scenarios of future waste management across the EU-21 that will form the basis of the environmental and economic analysis. We will consider the Landfill Directive Plus countries and the Landfill Directive Only countries separately at first. Policy on landfilling of plastic wastes that go beyond the regulations in the Landfill Directive will determine the extent to which waste diverted from incineration will be forced into recycling, or will simply move to landfill.

2.5.1 'Business as Usual' situation

The starting point for developing the future PVC waste management scenarios is the current destination of PVC wastes across Western Europe, provided by APME[1], and the rate of MSW incineration. We have assumed that for all waste streams (other than the minor group labelled 'other' wastes in this study), the present day incineration rate is in proportion to the general rate for MSW incineration. PVC wastes in the minor 'other' category consists of roughly equal amounts of medical and agricultural waste. We assume that all of the agricultural waste will continue to go to landfill, whilst the medical waste will all be incinerated with other clinical wastes. A rate of 50 per cent for incineration has therefore been adopted over the entire twenty-year horizon of the project. Errors arising from this source will not have a significant impact on the overall results, given that 'other' wastes account for less than two per cent of total post-consumer PVC waste arisings (see Figure 2 and Appendix 1).

Predicting the extent of PVC incineration in the future is uncertain, given the difficulties in predicting the impact and evolution of Member State legislation on landfilling of plastic wastes, and the subsequent development of recycling and incineration facilities to cope with waste diverted from landfill. In the case of the Landfill Directive Plus countries over the next decade, we envisage a major increase in incineration capacity in order to reduce reliance on landfilling for those residual wastes that cannot be recycled. Many of the proposed measures are due to come into effect within the next five years (Table 1). However, it is reasonable to assume that some delay in implementation comes about before landfill bans are fully operational and capacity has been developed to process waste diverted from landfill. A complete cessation of landfilling PVC waste within this group of countries is therefore highly unlikely. Taking these factors into account, we propose that the most optimistic baseline business as usual case (BAU) for the Landfill Directive Plus countries will result overall in 70 per cent of non-recycled PVC waste going to incineration by 2010, increasing to 80 per cent by 2020. This is characterised as the '*high incineration*' future. These data are shown in the upper section of Table 5, on the next page.

An alternative view of the future for the Landfill Directive Plus countries adopts a lower rate of incineration for these countries overall. In this case, proposed restrictions on landfilling plastic wastes result in a lower rate of increase in incineration - in which these countries reach only 60 per cent incineration by 2010 and 70 per cent by 2020 (the '*low incineration*' future) – see the middle section of Table 5.

The Landfill Directive Only countries are also expected to increase incineration capacity over the next two decades. Here we assume that the final rate achieved will be lower than for the Landfill Directive Plus countries because of the lower starting point and the poorer economic circumstances of some of the countries concerned. We anticipate also wide variation between countries in this group. For example, the UK currently incinerates about 12 per cent of MSW, but has recently announced a new waste management policy framework that may, incidentally to encouraging minimisation and recycling of waste, increase incineration to 20-40 per cent by 2020[15]. Spain is also planning to increase incineration in parallel with phasing out unmanaged waste dumping. This may be compared with other countries such as Greece, Portugal, and Ireland that currently have little or no incineration capacity. Taking these factors into account, we therefore propose under the BAU that the Landfill Directive Only countries increase incineration of non-recycled PVC waste by 2020 to levels equivalent to the 1997 rates in the Landfill Directive Plus countries (see Table 5, lower section). In the absence of bans affecting plastic wastes to landfill in these countries, we anticipate that the incineration of PVC constructional wastes will reach only 10 per cent by 2020. A linear trend is used between 2000 and 2020.

The incineration rates used to generate the BAU position are given in Table 5. The rates refer to the percent of PVC waste *that is not recycled* that goes to incineration (with energy recovery). For BAU, we assume that mechanical recycling develops as predicted under the 'Trend' scenario in the mechanical recycling study[4].

Table 5: Predicted incineration rates for PVC waste under Business as Usual

Non-recycled PVC waste to incineration						
	1997	**2000**	**2005**	**2010**	**2015**	**2020**
Landfill Directive plus - High EfW incineration						
Construction	0%	10%	40%	70%	75%	80%
Packaging	22%	50%	60%	70%	75%	80%
H&C	26%	20%	60%	70%	75%	80%
E&E	11%	20%	60%	70%	75%	80%
Auto	21%	30%	60%	70%	75%	80%
Other	50%	50%	50%	50%	50%	50%
Landfill Directive plus - Low EfW incineration						
Construction	0%	10%	30%	60%	65%	70%
Packaging	22%	50%	55%	60%	65%	70%
H&C	26%	20%	40%	60%	65%	70%
E&E	11%	20%	40%	60%	65%	70%
Auto	21%	30%	45%	60%	65%	70%
Other	50%	50%	50%	50%	50%	50%
Landfill Directive only						
Construction	0%	2%	5%	5%	8%	10%
Packaging	4%	5%	7%	11%	16%	22%
H&C	3%	5%	10%	13%	19%	26%
E&E	2%	3%	4%	5%	8%	11%
Auto	3%	5%	7%	10%	16%	21%
Other	50%	50%	50%	50%	50%	50%

The assumptions on which the Trend scenario was based are summarised in Figure 4. Overall recycling of post-consumer PVC waste will increase from about 3 per cent today to about 9 per cent by 2020. Feedstock recycling costs are currently higher than mechanical recycling, although feedstock recycling could compete with low quality mechanical recycling of packaging. An expansion of feedstock recycling is therefore assumed not to increase the total amount of PVC that may be recycled. The remaining waste that is neither incinerated nor recycled is assumed to go to landfill.

Figure 4: The 'Trend' scenario for mechanical recycling.

See reference 4 for details.

The ‘Trend’ recycling scenario developed by Prognos is based on the overall assumption that no new additional measures (legal, administrative and voluntary) beyond those already in force or in preparation are introduced to promote PVC recycling. The major specific assumptions referred to by the study are:

Regulations. EU and Member State regulations on landfilling, incineration, end-of-life vehicles and packaging will be implemented and maintained as planned. Additional regulations on electronic and electrical wastes will be put into effect. Recycling of PVC will be stimulated directly by these measures affecting packaging and electrical wastes and indirectly by restrictions on, and increasing cost of, landfill and incineration. Existing standards relating to cadmium, lead and PCB in recycled material, which may act as a barrier to PVC recycling, will not be tightened.

Voluntary measures. Existing voluntary systems for PVC recycling will be maintained and upgraded so that costs ‘remain at a level not too far from economic competitiveness’. Major existing recycling schemes for pipes, window profiles and flooring in Austria, Germany, Italy, Denmark, the Netherlands and the UK will be maintained or upgraded in step with increases in waste arisings, whilst those for roofing and bottles will be closed down, because of high logistic costs (roofing membranes) and substitution of PVC by PET (bottles).

Other assumptions. The price of virgin PVC recovers, so that by 2020 it will be at least on the level of the present ten-year average. Technical standards that presently restrict the use of recyclate in pipes will be changed so that high quality recycling of PVC pipes will be possible in all Member States in due course.

Percentage of ‘chosen’ recycling rates (see second column of Table 4 in Section 2.4.1) achieved:

High quality recycling		
	Pipes	40 per cent
	Windows	70 per cent
	Flooring	50 per cent
	Others	0 per cent
Low quality recycling		
	Cables	80 per cent
	Electronic	80 per cent
	Packaging	100 per cent
	Others	0 per cent

It is assumed that the above potential recycling rates are achieved by 2010 and continue to 2020. Present day proportions of potential recycling rates are taken as: 20 per cent for bottle, other rigid packaging applications and electrical products, 10 per cent for flooring, 15 per cent for pipes and 30 per cent for windows. Present day rates are assumed to increase linearly up to 2010, with the exception of bottle recycling, which is assumed to be phased out by 2005. Potential for cable recycling is assumed to remain at 80 per cent throughout the study period.

2.5.2 The scenarios

Having established the baseline BAU from estimated future incineration rates and predicted recycling rates based on a continuation of present day trends (as described under the ‘Trend’ scenario developed in the mechanical recycling study) we can now go on to develop alternative scenarios for diversion of PVC from incineration. Three alternative scenarios are developed in this study for comparison with BAU. The first two are based on the assumption that PVC diverted from incineration will go to recycling. However, as explained below, the capacity for recycling to absorb PVC diverted from incineration is limited. A third scenario, in which diverted waste is sent to landfill, has therefore been developed.

The scenarios are as follows:

Scenario 1: This scenario is partly based on the 'Selective Improvements' scenario proposed in the mechanical recycling study[4] (see Figure 5), but excludes high quality recycling of PVC in the household and commercial waste category and flexible profiles and hoses (construction category) for recycling. The recycling study was unable to estimate typical costs for recycling these product groups. It is reasonable to assume that development of recycling potential for these wastes is therefore further away than for the remaining wastes for which cost estimates were provided. However, low quality recycling of electrical and electronic wastes which is assumed to occur under the Trend scenario is assumed to continue under Scenario 1. Scenario 1 is therefore based on the assumption that all remaining wastes listed in Table 4 for which high quality recycling is feasible achieve 100 per cent of the chosen value for recycling by 2010, increasing from the same starting point as under the BAU scenario. Low quality recycling develops as described under BAU.

Figure 5: The 'Selective Improvements' scenario for mechanical recycling. See reference 4 for details.

The 'Selective Improvements' recycling scenario is based on the overall assumption that additional measures will be enforced selectively to encourage PVC recycling in areas with clear environmental benefits, but high recycling costs will act as a significant barrier. As a result:

Recycling of all wastes suitable for high quality recycling is encouraged and recycling of these wastes achieves the full potential shown by the 'chosen' values for recycling rate (shown in parentheses in the second column of Table 4).

For wastes suitable for low quality recycling, the following proportions of the maximum potential ('chosen') rates were used:

Cables	80 per cent
Electronic	80 per cent
Packaging	100 per cent
Other	0 per cent

It is assumed that these rates are achieved by 2010 and continue to 2020. Present day rates are assumed to increase linearly from 2000 to 2010.

Scenario 2: This scenario models mechanical recycling for all suitable waste achieving its absolute full potential in 2010 and continues at this rate until 2020. In other words, all waste streams are recycled at the *maximum* of the range for recycling potential shown in the second column of Table 4, rather than the 'chosen' rate used in scenario 1. We selected the maximum rate to maximise the differentiation between this scenario and scenario 1.

Scenario 3: In this scenario, we assume that environmental concerns over PVC incineration are sufficient to force the removal of PVC waste that cannot be recycled from incinerator feedstock. Recycling rates remain at the BAU level and all PVC in construction waste that cannot be recycled is landfilled. This waste stream was selected because PVC components form an easily recognisable and significant component of the non-masonry waste and are therefore potentially easy to isolate from other materials. Segregation of masonry wastes from other construction wastes is necessary if they are to be re-used as secondary aggregates, in line with current trends[8]. In contrast, segregation of PVC from the other waste streams considered in this study is likely to be more problematic.

2.5.3 PVC waste destinations

The PVC waste destinations are summarised for the scenarios for both high and low incineration futures in tabular form (Table 6) and are shown graphically in Figure 6. The quantities of waste recycled under BAU (and scenario 3, which is identical in terms of recycling rate), at 563 ktonnes/year, are in good agreement with the predicted rates by the recycling study, which showed recycling to reach 540 ktonnes/year in 2020. The level of recycling shown under the maximum recycling scenario (scenario 2), which reached 1,436 ktonnes/year in 2020 is somewhat higher than the corresponding maximum rate from the recycling study, at just over 1,200 ktonne/year. However, these latter calculations were made using the 'chosen' recycling rates in Table 4, rather than the maxima. In 2020, recycling rates are predicted to have increased to 15.4% under scenario 1 and to 22.4% under scenario 2.

The destination of PVC waste under BAU and the three scenarios is shown in Figure 6 for high and low incineration futures. To interpret the graphs, we will first consider the *area* plots (as opposed to the *line* plots). These show (reading up from the bottom of each of the area graphs) the amount of PVC recycled, incinerated with energy recovery or landfilled across the EU-21, under BAU and each of the three diversion scenarios. The sum of the coloured areas in each graph corresponds with the total arisings of post-consumer PVC waste. Higher rates of PVC recycling under scenarios 1 and 2 (compared with BAU) draw PVC away from incineration and landfill in proportion to how much PVC is going to these options under BAU. As a result, the area plots for both incineration and landfilling reduce under scenarios 1 and 2, with a concomitant increase in the recycling area plots. For scenario 3, where non-recycled PVC in construction waste is diverted from incineration to landfill, the incineration area decreases, the landfill area shows an equivalent increase and the recycling area remains unchanged from BAU.

The different rates of PVC landfilling and incineration between Landfill Directive Plus and Landfill Directive Only countries are indicated by the *lines* plotted within the landfill and incineration areas of the graphs. The regions below the lines show the amount landfilled or incinerated in the Landfill Directive Only countries: the regions above the lines are the corresponding amounts for the Landfill Directive Plus countries. This distinction is omitted for recycling in the interests of clarity. Note that only the Landfill Directive Plus countries are sub-divided into high and low incineration futures. Further details of the fate of various PVC applications that make up the waste streams examined here are given in Appendix 1, for 2000 and 2020.

Table 6: Summary of waste destinations - EU-21, ktonnes/y.

	2000	2005	2010	2015	2020
BAU					
high incineration					
Incineration	516	1,198	1,731	2,302	2,938
Landfill	2,970	2,610	2,501	2,753	2,907
Recycling	94	198	369	470	563
BAU					
low incineration					
Incineration	516	925	1,513	2,042	2,637
Landfill	2,970	2,883	2,719	3,013	3,207
Recycling	94	198	369	470	563
Scenario 1					
high incineration					
Incineration	516	1,177	1,631	2,155	2,740
Landfill	2,970	2,542	2,345	2,557	2,678
Recycling	94	287	625	813	989
Scenario 1					
low incineration					
Incineration	516	909	1,427	1,913	2,462
Landfill	2,970	2,810	2,549	2,799	2,956
Recycling	94	287	625	813	989
Scenario 2					
high incineration					
Incineration	514	1,136	1,507	1,983	2,519
Landfill	2,957	2,451	2,161	2,347	2,453
Recycling	110	418	932	1,195	1,436
Scenario 2					
low incineration					
Incineration	514	879	1,319	1,761	2,264
Landfill	2,957	2,709	2,350	2,569	2,708
Recycling	110	418	932	1,195	1,436
Scenario 3					
high incineration					
Incineration	448	896	1,138	1,510	1,953
Landfill	3,039	2,912	3,094	3,545	3,891
Recycling	94	198	369	470	563
Scenario 3					
low incineration					
Incineration	448	691	1,000	1,346	1,763
Landfill	3,039	3,117	3,232	3,709	4,081
Recycling	94	198	369	470	563

Figure 6: PVC waste destinations, ktonnes/year

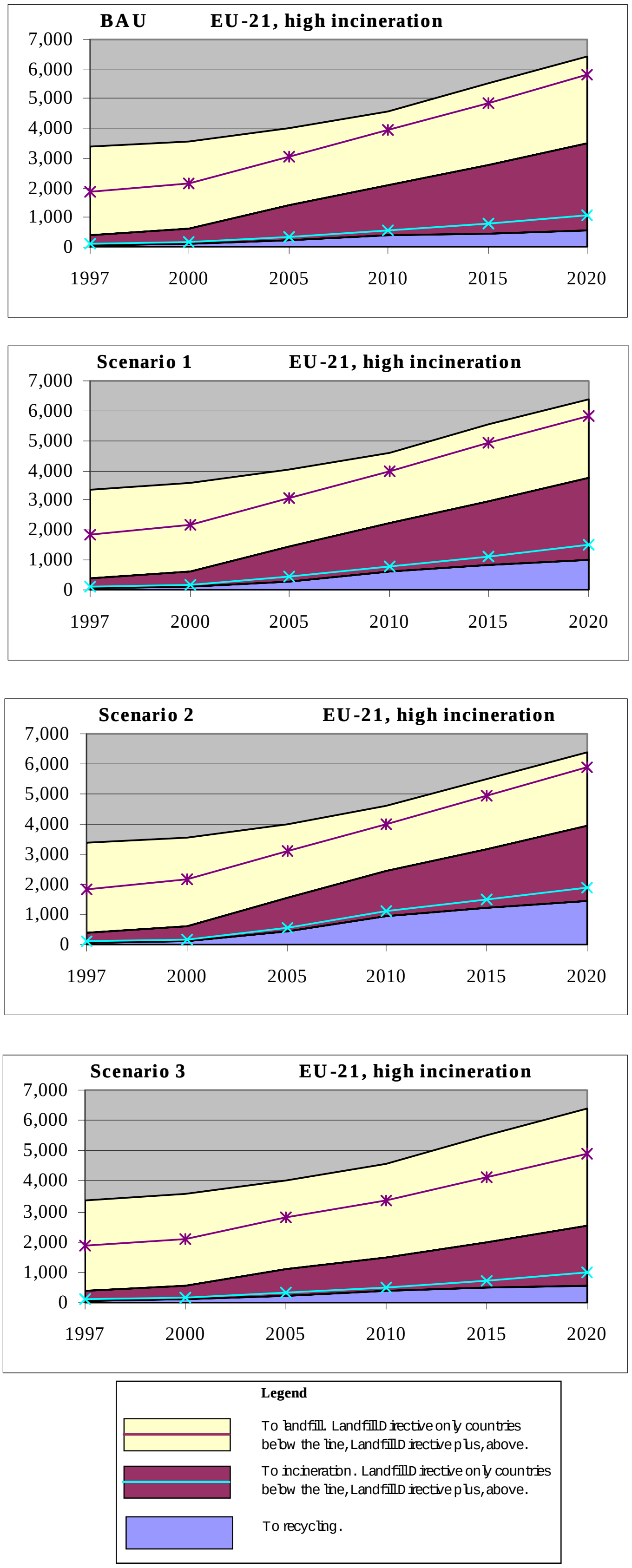
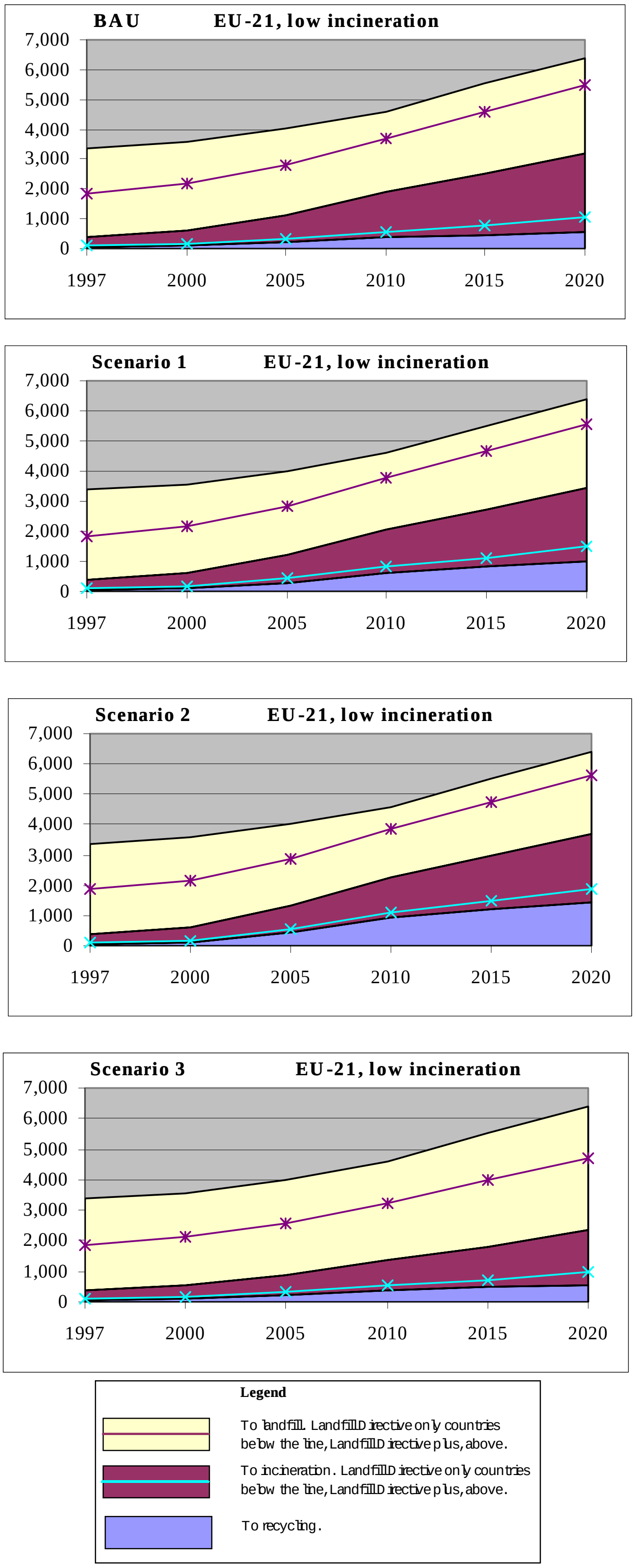


Figure 6: PVC waste destinations, ktonnes/year - continued



Having determined the time trends for PVC to landfill, incineration and recycling, we can now calculate the total cumulative amounts of PVC waste going to each of these options over the time horizon of the study (2000-2020) – in other word, the total PVC waste to each option summed for each year between 2000 and 2020. The cumulative waste arisings data are illustrated in Appendix 2, which shows details of the waste destinations under the alternative scenarios. The overall cumulative destinations of PVC waste are shown in Table 7. The diversion rates achieved are summarised in Table 8. Table 9 shows the specific products whose recycling rates will increase under scenarios 1 and 2.

Table 7: Cumulative destinations of PVC waste 2000-2020, relative to BAU, ktonnes.

Waste management option	Scenario 1	Scenario 2	Scenario 3
		Rigid PVC	
High incin future			
Incineration	-1,611	-2,681	-4,408
Landfill	-2,337	-3,696	4,408
Recycling, high quality	3,948	6,041	0
Recycling, low quality	0	337	0
Low incin future			
Incineration	-1,405	-2,345	-3,826
Landfill	-2,543	-4,032	3,826
Recycling, high quality	3,948	6,041	0
Recycling, low quality	0	337	0
		Flexible PVC	
High incin future			
Incineration	-221	-1,392	-6,656
Landfill	-338	-1,998	6,656
Recycling, high quality	558	1,840	0
Recycling, low quality	0	1,551	0
Low incin future			
Incineration	-192	-1,203	-5,745
Landfill	-367	-2,188	5,745
Recycling, high quality	558	1,840	0
Recycling, low quality	0	1,551	0

Note: Negative values indicate a diversion away from the specified option.

Table 8: Overall diversion rates (from incineration & landfill) relative to BAU, 2000-2020, ktonnes (per cent diverted compared with BAU).

	Scenario 1	Scenario 2	Scenario 3	
Diversion to recycling	4,507 (5%)	9,768 (11%)		
			High incin future	**Low incin future**
Diversion to landfill			11,064 (32%)	9,571 (32%)

Table 9: Cumulative increase in recycling compared with BAU, 2000-2020, ktonnes

Application	Product type	Scenario 1	Scenario 2	High / Low quality
Rigid				
Constr	Pipes	968	1,095	H
Constr	Window profiles	395	524	H
Constr	Profiles - cable trays	147	184	H
Constr	Other profiles	2,439	3,048	H
Packaging	Other rigid packaging products		343	L
H&C	Printed films	0	303	H
H&C	Sheets, chemical equipment	0	162	H
H&C	Miscellaneous sheets	0	263	H
H&C	Miscellaneous rigid profiles	0	255	H
H&C	Other rigid products	0	200	H
	Total Rigid	**3,948**	**6,378**	
	Rigid to high quality recycling	**100%**	**95%**	
Flexible				
Constr	Cables	0	253	L
Constr	Flooring, calandered	558	788	H
Constr	Profiles and hoses	0	472	H
H&C	Shoe soles	0	384	H
H&C	Various flexible products	0	196	H
E&E	Cables	0	985	L
E&E	Adhesive tapes	0	146	L
E&E	Injection moulded parts	0	167	L
	Total Flexible	**558**	**3,390**	
	Flexible to high quality recycling	**100%**	**54%**	
	Total Flexible plus Rigid	**4,507**	**9,768**	

3 Model development

A spreadsheet model was developed to calculate burdens and credits, together with financial costs, associated with achieving each of the scenarios described in the previous section. Here we outline the baseline assumptions that underpin the model's operation.

3.1 IMPACTS ANALYSED

A partial life cycle analysis was undertaken of the principal environmental burdens and credits associated with moving from BAU to the three diversion scenarios. Impacts from the following processes were considered in the analysis:

- Incineration of PVC (and of MSW that may replace diverted PVC at the incinerator);
- Landfilling of PVC and residues from its combustion (and impacts associated with MSW that may be displaced as a result of diverting PVC);
- Impacts associated with manufacture of reagents needed to control hydrogen chloride emissions from incinerators;
- Impacts of PVC recycling;
- Impacts associated with PVC resin manufacture that are avoided by recycling;
- Transportation of wastes, residues and reagents.

A full life cycle analysis of the PVC waste management system is beyond the remit of the present study, although we believe that the most important impacts have been identified in the present restricted analysis. Table 10 shows the specific impacts for which quantitative data are available and have been included in this study, together with the impacts for which externalities have been analysed.

Table 10: Quantified environmental burdens included in this analysis

Burden	Incineration (direct impacts)	Incineration (Indirect impacts) Reagent manufacture	Landfill	Recycling / PVC manufacture	Transportation	Included in externality analysis
Emissions to air:						
Dust	✓	✓		✓	✓	✓
HCl	✓	✓		✓		✓
NO_x	✓	✓		✓	✓	✓
SO_2	✓	✓		✓	✓	✓
Metals	✓	✓		✓		✓
Dioxins	✓					✓
Methane			✓			✓
CO_2	✓	✓		✓	✓	✓
Discharges to land						
PVC waste			✓			
MSW			✓			
Other wastes			✓	✓		
Plasticiser			✓			
Metals in PVC matrix			✓			
Incinerator residues			✓			
Energy						
Power /heat recovered	✓					✓
Energy use		✓		✓		✓
Other						
Reagent consumption	✓					✓
Road accidents					✓	✓

The next stage is to set the baseline conditions and assumptions for each of the processes listed above.

3.2 INTERACTIONS BETWEEN PVC AND MSW MANAGEMENT

PVC waste is assumed to be incinerated with the municipal waste stream in modern mass-burn incinerators that comply with the emission limits set out in the proposed new Incineration Directive. Since incinerator operators are under commercial pressure to maximise the utilisation of their plant, any PVC-containing wastes (eg mixed plastic wastes) that are diverted from incineration will nearly always be replaced by more MSW. Throughput of waste to an incinerator is generally limited by either the thermal load (heat input) or capacity (mass throughput of waste). The plant must therefore be operated within its design minima and maxima for thermal load and mass throughput. Where an incinerator is heat limited, replacing a relatively high heat value fuel such as PVC-containing waste with one of lower calorific value like MSW requires the throughput of the replacement waste to be increased to preserve the heat input, and thus maintain the revenue from energy sales. If the plant is mass limited, no more waste can be put through the plant, so replacement takes place on a mass-for-mass basis.

The calorific value of MSW has been increasing steadily over the last few years, as a result of larger proportions of plastic and paper in the waste stream. The resultant higher temperatures in the combustion chamber may result in excessive rates of corrosion if the heat input to the incinerator is not restricted – i.e. the plant becomes thermally limited. According to the study by TNO[16], this is now the situation with many MSW incinerators in the Netherlands, and, by implication, in other similar countries.

A few incinerators designed to accept waste of high calorific value, such as refuse-derived fuel (RDF) may become mass limited if such fuel is no longer available, perhaps because pre-treatment has been abandoned due to lack of markets. In such cases, mass throughput is limited by the capacity of the grate to convey waste through the combustion chamber.

A third possibility also exists, in which the plant is operating below design capacity, and hence the reduction in PVC would not be made up by replacement waste. This situation may persist for short periods due to temporary interruptions in waste supply. Some German incinerators are believed to be in this position since landfill charges in Germany are currently lower than of late in order to attract waste before the imposition of the restrictions on landfilling carbonaceous wastes in 2005, thus some incinerators may be experiencing difficulty in obtaining sufficient waste. Commercial pressures will, of course, stimulate the operator of such plant to maximise its utilisation.

So, PVC diverted from incineration may therefore be replaced by MSW on a heat or mass equivalent basis. We have therefore decided to look at the emissions attributable to the replacement waste in order to see if relevant impacts can be expected in from the analysis of externalities. We therefore calculate the emissions and other burdens/credits due to incinerating PVC under the BAU Scenario, and similar impacts from PVC plus any replacement MSW under the diversion target[j]. The net change from BAU is thence computed. Results are expressed on the basis of both thermal and mass replacement by MSW. Results are also shown for the situation where no replacement takes place – this indicates the impacts due solely to the change in PVC throughput.

We also need to take account of what would have happened to the MSW that replaces the diverted PVC at the incinerator. This MSW would have been landfilled, so as well as the burdens associated with incinerating this MSW, we need to deduct the burdens at the landfill. These relate principally to the formation of methane, a potent contributor to global warming, as the biodegradable components of MSW decay in the landfill. Replacing PVC at the incinerator with MSW therefore also removes these burdens due to MSW at the landfill.

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[j] We have to consider the composition of the MSW that replaces PVC. Clearly, if PVC is diverted from incineration as predicted under the three scenarios, then its contribution to the chlorine content of MSW will fall over time, although substantial amounts will still be incinerated, even in 2020 (see Table 6). We have not allowed for a change in the chlorine content of replacement MSW over the time horizon of the study. However, the impacts of a change of at most 1 or 2 kg Cl/tonne of replacement MSW, compared with PVC with a chlorine content of 338 to 541 kg Cl/tonne are trivial and can be safely ignored.

3.3 PVC AND MSW COMPOSITION

Information on the composition of PVC and replacement MSW forms the basis of estimating changes in environmental burdens associated with adopting the three alternative PVC waste management scenarios. The typical composition of rigid and flexible PVC formulations is shown in Table 11. The estimates were made from data provided by Titow[7] for representative PVC formulations, and agree well with the composition data used in a former study[16], from which the calorific value (CV) data were taken. Also shown is the amount of carbon dioxide of fossil origin released on combustion. This contributes to global warming and is taken into account in the burdens and externalities analysis.

Table 11: Estimated average composition of PVC compound

Component	Unit	Rigid	Flexible
PVC resin	kg / tonne	950	593
Plasticiser	kg / tonne	0	296
Cadmium (Cd) stabiliser	kg / tonne	0.095	0.059
Lead (Pb) stabiliser	kg / tonne	17	7.1
Inert filler	kg / tonne	33	104
Fossil CO_2 from incineration (a)	kg / tonne	1,393	1,673
Sulphur	kg / tonne	0	0
Chlorine (b)	kg / tonne	541	338
Calorific value (CV)	GJ / tonne	16.17	19.98

(a) All carbon is assumed to be of fossil origin. The CO_2 yield from incineration was based on a carbon content of 40 per cent for PVC resin and 76 per cent for plasticiser, assumed to be all DEHP. (b) Chlorine is assumed to originate entirely from PVC resin, which contains 57 per cent chlorine.

From the preceding discussion on the role of replacement MSW in the system under study, it is clear that information on MSW composition is also needed. This is given Table 12. The amount of fossil carbon dioxide released on incineration and an estimate of methane emission after landfilling are also shown. Non-fossil carbon dioxide is assumed by convention to be neutral in global warming terms and so is not considered further in this study.

Table 12: MSW composition and characteristics

(Data from reference 16 except where indicated otherwise)

Component	Unit	Quantity
Sulphur	kg / tonne	1.2
Chlorine	kg / tonne	6.38
Cadmium (Cd)	kg / tonne	0.0072
Lead (Pb)	kg / tonne	0.455
Fossil CO_2 from incineration (a)	kg / tonne	264
Incinerator residues – bottom ash (b)	kg / tonne	300
Incinerator residues – fly ash (b)	kg / tonne	24
Calorific value (CV)	GJ / tonne	10
Methane formation potential in landfills (c)	kg / tonne	30

(a) Based on data from the UK National Household Waste Analysis Programme[17], assuming all of the carbon in plastics and half of that in textiles and miscellaneous non-combustibles is of fossil origin – i.e. about 30 per cent of carbon in MSW is fossil, as opposed to contemporary.

(b) Bottom (or grate) ash and fly ash data from reference 3. Fly ash content ranges from 14 to 34 kg/tonne. The mean of this range is quoted above.

(c) See reference 24.

PVC concentrations in MSW vary considerably from country to country, as does MSW composition generally. Recent estimates range from 0.6 to 0.74 per cent PVC[3.] As a result, PVC contributes between about 38 to 66 per cent of the chlorine in MSW. In this study, we assume that 50% of chlorine in MSW originates from PVC. For metals, PVC is considered to make a significant contribution to only the cadmium content of MSW (accounting for about 11 per cent). For lead, the Bertin study concluded that the PVC contribution to MSW was about 1 per cent, although higher values have been reported in other studies. For other metals (zinc, tin, arsenic), the contribution from PVC to concentrations in MSW are less than 0.2 per cent.

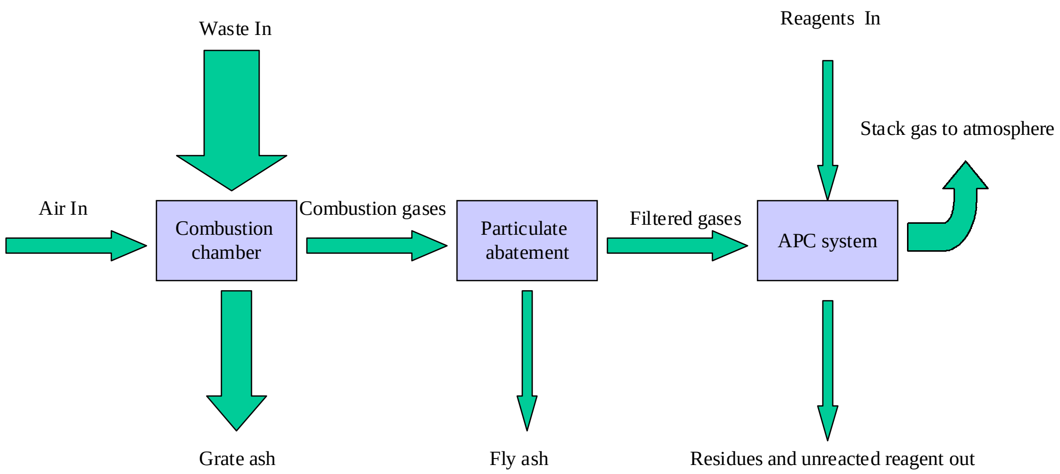
Armed with information on PVC and MSW composition, we can now calculate the environmental burdens and credits associated with implementing the scenarios. We start by considering the burdens avoided by diverting PVC waste away from incineration.

3.4 DIRECT BURDENS FROM INCINERATION

The direct burdens from incineration result from discharges of combustion products, residues and effluents to the atmosphere, land and water. The quantities and composition of these discharges depend on the composition of the waste, the design and operation of the incinerator and the relevant statutory emission limits and consents. We first provide an outline description of the incineration process and then consider the principal emissions and discharges.

Modern MSW incinerators are highly sophisticated plants with complex equipment required to meet present day emission limits. A vast range of designs and process layouts are available, although all plant has certain features in common. These are illustrated in a highly simplified form in the flow diagram in Figure 7.

Figure 7: Schematic diagram of MSW incinerator



Note: In some incinerators particulate removal takes place downstream of the APC system and fly ash and dry APC residues are collected together.

Waste delivered to the incinerator is tipped into a refuse pit and from there transferred by crane and grab into the feed chute to the combustion chamber. The burning waste is then conveyed through the combustion chamber by a variety of designs of moving grate systems. Non-combustible components plus ash are discharged into a water bath. These solid residues are known as grate (or bottom) ash. Grate ash is frequently recycled as a secondary aggregate for constructional uses. Air is introduced into the combustion chamber from below and above the burning waste mass and the combustion off-gases pass through a heat recovery section of the boiler before entering the first stage of the emission control system. In the heat recovery section, water is turned to steam that is then used to generate electricity via a steam turbine and/or is used for process or district heating. Fine particulate matter is then often removed from the combustion off-gases using a combination of cyclones, filters and electrostatic precipitators, to produce a fine solid residue called flyash[k]. The filtered gases then pass to the air pollution control (APC) system where further cleaning of the gas stream takes place before the stack gas is discharged to the atmosphere, sometimes after further removal of particulate matter. The APC uses a combination of reagents to remove specific pollutants. These include alkalis such as slaked lime (calcium hydroxide, $Ca(OH)_2$) and sodium hydroxide (NaOH) to remove acid gases and activated carbon to remove dioxins and other trace organic pollutants. Some systems, mostly smaller installations at present, also use powdered sodium bicarbonate ($NaHCO_3$) to absorb acid gases. Characteristics of representative acid gas control systems are described in Section 3.4.2, below. Reagents such as urea or amonia may also be introduced into the combustion gases to reduce oxides of nitrogen to comply with emission limits. For PVC combustion, the most significant reagents are alkalis for acid gas control.

In estimating environmental burdens from incineration, we need to take account of the distribution of the components in the waste between the combustion off-gases and solid residues. Elements are partitioned according to their volatility and reactivity. Chlorine in MSW is converted into hydrogen chloride gas and volatile salts during combustion. An appreciable proportion is absorbed onto alkaline ash particles and is so retained in the grate ash and fly ash before entering the air pollution control system. Sulphur is converted to sulphur dioxide and sulphate salts, some of which may also be retained by the ash residues. Neutralisation of acid gases in this way reduces the demand for alkaline reagents for the APC system, and so needs to be taken into account in estimating reagent consumption and residue production.

The distribution of chlorine, lead and cadmium has been reviewed in detail as part of the parallel study on PVC incineration[3], drawing on experimental studies and measurements on MSW incinerators. The study also reported limited data for this distribution of sulphur between bottom ash and the raw combustion, but provided no further information on the amount retained by the fly ash. An average of 50 per cent of sulphur was found to occur in the raw combustion gas. All of the chlorine coming from PVC is assumed to require neutralisation, whilst for MSW (where the non-PVC chlorine is mostly present as alkali and alkaline earth metal chlorides of high thermal stability), only 70% is estimated to enter the APC system, the remainder being neutralised by grate and fly ash[3]. Note that considerable variation has been reported around the average values shown here, depending on waste composition and plant design and operation. For example, volatilisation of chlorine from waste during incineration was found to vary from 70 to 90 per cent and for sulphur, from 30 to 60 per cent. For lead and cadmium percentages of 63% and 18% have respectively been taken for the grate ash, whilst the remaining quantities are found in the flyash (37% for lead and 82% for cadmium). Lead and cadmium are found in APC residues or stack gases only in trace quantities[18].

[k] As well as grate ash and fly ash, small amounts of solid residue may collect in other parts of the combustion systems. These are included with grate ash in this study.

3.4.1 Discharges to atmosphere

The principal discharges in terms of mass to atmosphere from waste combustion are carbon dioxide and water vapour. All of the carbon in PVC or MSW that is incinerated is assumed to be converted to carbon dioxide and discharged at the rates shown in Table 11 and Table 12.

For other species emitted to atmosphere, there is very little data to support the contention that the combustion of PVC waste with MSW affects the composition of the discharged stack gas in a consistent and systematic way. It is not possible therefore to estimate changes in burdens associated with incinerator emissions to air by comparing discharge concentrations. Instead, we take as the starting point the statutory emission limit value (ELV) for the pollutants in question and use it to work out the resultant emission burden, from knowledge of the air throughput needed for combustion of unit mass of waste. Implicit in this method is the assumption that species are emitted at the relevant ELV. In practice, many emissions will be significantly below this level, but the ELV value will set the maximum burden that can originate from this route. The approach does, however, become somewhat unreliable when comparing emissions from PVC and MSW and the results obtained for this part of the analysis must be treated with caution.

We have assumed in this study that the emission limits set out in the proposed Incineration Directive will apply, and that all emissions will take place at their limit value. In practice, lower emission concentrations will apply, and Member States may also set more stringent limits nationally or for particular incinerators. The relevant proposed Incineration Directive ELV concentrations are shown in Table 13.

Table 13: Stack gas emission limit values (ELV) under the proposed Incineration Directive

Species	Units (dry gas at 11% vol. oxygen)	Emission limit value (a)
Total dust	mg / Nm^3	10
Hydrogen chloride	mg / Nm^3	10
Nitrogen oxides	mg / Nm^3	200
Sulphur dioxide	mg / Nm^3	50
Cadmium and thallium	mg / Nm^3	0.05
Lead and other metals – (b)	mg / Nm^3	0.5
Dioxins	ng I-TEQ/Nm^3	0.1

(a) ELVs for dust, hydrogen chloride, sulphur dioxide and nitrogen oxides (as nitrogen dioxide) are daily averages. Metal ELVs are averages over 0.5 to 8h sampling periods.

(b) The ELV for lead also includes antimony, arsenic, chromium, cobalt, copper, manganese, nickel, and vanadium.

Note that the emission limits given in Table 13 refers to *concentrations*, not mass fluxes. The mass flux from the stack is the product of the concentration of the emitted species and the air throughput, which is typically about 5000 - 5500 Nm^3/tonne of waste. Stack gas emissions have therefore been calculated from the following equation:

$$E_i = ELV_i \times V$$

where E_i is the emission per tonne of waste incinerated for species i, ELV_i is the corresponding emission limit value for species i, V is the volumetric throughput of air in

Nm^3/ tonne of waste incinerated. In line with previous work[19], a value of 5,060 Nm^3/ tonne has been adopted for *V*.

Emissions to atmosphere of species controlled by ELVs are discussed in the following sections.

Dust

Dust is removed from the stack gas with a combination of filters and electrostatic precipitators and some may also be removed with APC residues. The dust consists of mineral particles enriched in volatile metals and other elements and traces of soot from incomplete combustion. Dust emissions are essentially a function of the operation of the facility and are not determined by fuel composition within the usual operating range. All dust emissions are assumed to be in the form of particles of less than 10 micrometers diameter (PM_{10}).

Lead and cadmium

Metals are emitted bound to traces of dust that escape removal from the combustion gases. The proposed Incineration Directive does not stipulate individual limits for cadmium or lead. Instead, combined limits are set with other metals, namely 0.05 mg/m^3 for cadmium and thallium, and 0.5 mg/m^3 for lead together with eight other metals and metalloids (Table 13). For present purposes, we have treated these limits as though they apply just to the metals of interest in this study – cadmium and lead. Our calculations of emissions of cadmium and lead in incinerator stack gases will therefore significantly over-estimate actual emissions and must be treated as an upper limit. However, as explained in section 6.2, this simplification has no significant impact on the outcome of the environmental analysis.

Nitrogen oxides

Nitrogen oxides (principally emitted as nitrogen monoxide, NO, which oxidises to the more toxic nitrogen dioxide, NO_2, in the atmosphere) originates from combustion of nitrogen compounds in the waste (*fuel* NO_x) and from high temperature oxidation of nitrogen in the combustion air (*thermal* NO_x). PVC contains only negligible amounts of nitrogen, so effectively all of the NO_x from this source will be of thermal origin. In MSW, which does contain appreciable amounts of organic nitrogen compounds, about half the NO_x is of fuel origin, the rest thermal. The balance does depend on combustion conditions, with higher temperature favouring thermal NO_x formation. NO_x emissions can be controlled by managing combustion conditions and through the use of reductants such as ammonia or urea. We have not further considered the differences in demand for NO_x abatement reagents between PVC and MSW in this study because of the lack of information on the effects of PVC on emissions and the estimated negligible impact of differences in the costs of emission abatement between PVC and MSW.

Hydrogen chloride and sulphur dioxide

Control of acid gas emissions is of major importance for PVC incineration, given that one tonne of pure PVC would produce almost 600 kg of hydrogen chloride. (This compares with about 7 kg of HCl per tonne of MSW). Emissions can be effectively controlled by modern APC systems, described below. MSW also contains sulphur that produces sulphur dioxide (SO_2) on combustion, which also requires abatement. In contrast PVC compounds contain only traces of sulphur and so produce negligible amounts of SO_2.

Dioxin

Trace quantities of potentially toxic organic compounds may also be formed during the combustion process and in the off-gases as they leave the combustion chamber and pass through the various stages of air pollution control, before discharge in the stack gas or with fly ash. The most significant of these pollutants are the family of polychlorinated dibenzo-*p*-dioxins and the related furans, collectively known for short as 'dioxins'. There has been considerable debate as to whether removal of chlorine containing components of MSW (such as PVC) prior to combustion contributes to a reduction in chlorinated dioxin emissions. This proposition has been analysed in an authoritative review by Eduljee and Cains[20], who conclude that *'as a strategy for controlling PCDD/F formation, (the) removal of chlorine-containing materials such as PVC is unlikely to prove effective'*. For this study, we work on the assumption that there is no relationship between PVC combustion with MSW and dioxin release, although this view may change in the light of further study. In any case, incinerators operators are obliged to comply with the statutory emission limit and will therefore operate the combustion system and activated carbon injection system (that removes dioxins) to ensure regulatory compliance. Similarly, we have excluded dioxins in incinerator residues from analysis in this study.

3.4.2 Acid gas emission control

Acid gas control is an important issue for PVC combustion. Systems for controlling acid gas emissions have been reviewed extensively by the Bertin study on PVC incineration[3]. The characteristics of the main systems they reported are summarised in Appendix 3.

The deployment of APC systems in European incinerators over 30 ktonnes/year capacity has been reported in 1997[21] as follows, on a mass throughput basis:

Dry systems	14 per cent;
Semi-dry systems	22 per cent;
Wet, including semi wet-wet	64 per cent.

Since this listing of plant was compiled, a large number of old, smaller incinerators (especially in France and UK) have closed. Many of these were equipped with dry APC systems based on calcium oxide or calcium carbonate.

Whilst predicting the future is always uncertain, we have based estimates of burdens from acid gas control on the assumption that over the next twenty years, acid gas abatement will use 25 per cent semi-dry systems and 75 per cent wet processes. We further assume that with the strengthening of consents for liquid effluent discharges, two-thirds of all wet systems will be semi wet-wet systems – i.e. liquid effluents will be eliminated by evaporation and salts discharged in dry form (see Table 14). In addition, newer systems are gaining momentum, for example dry systems based on the use of powdered sodium bicarbonate[1] and wet systems which recover hydrogen chloride solution as a commercial product. These systems are currently at a low level of deployment for large scale MSW incinerators compared with more traditional approaches to acid gas control. They have therefore been omitted from further consideration in the scenario evaluation. However, the performance of these systems in terms of reagent demand and residue disposal is reported later for comparison with semi-dry and wet systems.

[1] eg the 'Neutrec' system developed by Solvay.

The amount of reagent used by the APC system is controlled by the stoichiometric ratio, SR. SR is the ratio of reagent required to achieve a given emission limit in practice, compared with the theoretical (or *stoichiometric*) quantity predicted by the relevant chemical reactions. SR values estimated by the Bertin team are used in this study and are reported in Table 14.

We also need to take account of the relative usage of calcium and sodium hydroxide in wet APC systems. The Bertin study reported four out of five plants investigated used a calcium hydroxide to sodium hydroxide ratio of 75 per cent / 25 per cent for neutralisation in wet systems. We have adopted this proportion here (see Table 14). The remaining system they described used a ratio of 88 per cent / 12 per cent.

Table 14: Estimated deployment of acid gas control systems, 2000-2020.

Parameter	Semi dry systems	Wet systems
Deployment	25%	75% (50% semi wet-wet, 25% wet)
SR(a), hydrogen chloride	1.7	1.1
SR, sulphur dioxide	4.0	1.1
Absorbent	Calcium hydroxide	Calcium hydroxide (75%) Sodium hydroxide (25%)
Products (sulphates from MSW only)	$CaCl_2.2H_2O$ $CaSO_4.2H_2O$	$CaCl_2.2H_2O$ NaCl $CaSO_4.2H_2O$ Na_2SO_4

(a) SR = stoichiometric ratio

3.4.3 Residues and reagents

Grate ash and fly ash

Quantities of grate ash and fly ash from MSW incineration are reported in Table 12 in Section 3.3. In the case of PVC, where the inert component is mostly fillers (Table 11) released as powder during combustion, we have no information on the distribution of this residue between the grate and fly ash. This is likely to depend strongly on the operating conditions at the plant, especially on the rate and source of air supply. In the absence of better information, we have assumed that the inerts in PVC are evenly distributed between the grate and fly ash fractions. The mass of grate and fly ash is increased by the absorption of acid gases.

Fly ash and APC residues are treated as hazardous waste and require disposal in facilities licensed to take hazardous waste. The residues are often stabilised by mixture with cement or bitumen to improve the structural integrity and reduce the potential for leaching of heavy metals. In Germany, such wastes are often disposed of in disused salt caverns.

A significant fraction of grate/bottom ash is used as a secondary aggregate in construction purposes and so does not require disposal. This needs to be taken into account in the analysis of burdens. Grate ash usage rates vary markedly between countries. Highest rates of use (almost 100 per cent) are seen in the Netherlands, with Denmark using about 70 per cent and Germany and France about 50 per cent each[22]. In contrast, Sweden was reported as having zero usage rates, while UK rates are estimated at less than 25 per cent. Future EU trends in grate ash use will depend on increasing pressures to recycle, but concerns over leachable heavy metals may tend to discourage recycling. Taking these factors into account, an average rate of recycling of incinerator grate ash of 60 per cent over the next 20 years for the EU-21 would seem reasonable.

Air Pollution Control System Reagents and Residues

Reagent use and residues produced from PVC or MSW incineration have been calculated by:

- Determining the amount of chlorine and sulphur in the waste entering the incinerator, from the concentrations given in Table 11 and Table 12;
- Determining the proportion of acid gases requiring neutralisation in the APC system;
- Calculating the distribution of acid gas neutralisation between semi-dry and wet systems, and the proportion neutralised by calcium or sodium hydroxide (in the case of wet systems) from Table 14;
- Finally, calculating the quantities of reagent used, salts produced and unreacted reagent using the factors set out in Appendix 3.

3.5 INDIRECT BURDENS OF INCINERATION

In addition to the emissions and discharges that occur directly from incineration that have been outlined above, additional indirect burdens stem from the production of APC reagents and the transportation of reagents and residues. Transportation burdens affect wastes diverted to and from landfill and recycling and so are not specific to incineration. Transportation issues are discussed together in Section 3.9. In the following section, we review the burdens from APC reagent manufacture.

3.5.1 Burdens from APC reagent manufacture

Lime is manufactured by heating limestone (calcium carbonate), causing it to decompose into calcium oxide (CaO – quick lime) and carbon dioxide, a process known as *calcination* The quick lime is reacted with water to form calcium hydroxide for use in APC systems.

There is a multiplicity of processes used for lime making but most follow the following three stages preheating, calcining and cooling. The heat consumption (from solid, liquid or natural gas fuel) is typically between 4.6 – 7.5 GJ/tonne of lime for rotary kilns and 3.6 – 5.0 GJ/tonne for shaft kilns. Electricity consumption ranges from 4-45 kWh/tonne for shaft kilns to 17-100 kWh/tonne for rotary kilns. Lime making is not currently subject to EU-wide emission limit values, and it is up to Member States to set their own limits. Emissions will therefore vary widely from facility to facility, depending on type of process, fuel and national emission limits. The emission factors in Table 15 were estimated for coal-fired lime kilns, and may not be truly representative of EU emissions. Note that the values given relate only to the process itself and do not include upstream burdens, such as those associated with limestone extraction. The data do, however, allow us to make a preliminary estimate of the importance of lime making as a contributor to PVC incineration burdens.

Somewhat more complete data on environmental burdens from sodium hydroxide manufacture is available, produced as part of a study on inputs and outputs of PVC manufacture[23]. The most important emissions to air for this study are shown in Table 15. Other burdens given in Appendix 4.

Table 15: Air emissions from manufacture of APC reagents, kg/tonne.

Burden	Lime	NaOH
CO_2	1,000	1,120
NO_x	0.18	7.2
Dust	n/a	3.1
SO_2	2.66	10
HCl	n/a	0.15
Metals	n/a	0.002

Note that the burdens in this case include all upstream processes used to produce a unit mass of sodium hydroxide (from electrolysis of brine) traced back to the extraction of all the fuels and other minerals involved from the earth. It is important to note that sodium hydroxide is a co-product of chlorine manufacture, that is then used to make PVC. The inputs and outputs of PVC and sodium hydroxide manufacture must therefore be partitioned between the various co-products. This partitioning has already been undertaken for the data shown in Appendix 4, but as the study author points out, there is no single method of partitioning that meets with universal approval.

3.6 BURDENS FROM LANDFILLING

Burdens from landfill of interest in this study include:

- Changes in the quantity of PVC and MSW landfilled as a result of implementing the scenarios;
- Consequential changes in the burdens of PVC components (resin, plasticisers and metallic stabilisers) sent to landfill, and
- Emissions of greenhouse gases from landfilled waste.

Changes in the quantities of waste landfilled under the three scenarios are derived from the diversion data presented in Section 2.5.2. Burdens per tonne of PVC or MSW landfilled have already been reported as average concentrations in Table 11 and Table 12. Disposal to landfill is assumed to be entirely to modern sanitary landfills with effective measures to prevent the escape of leachate into surrounding strata, and having leachate collection and treatment facilities so that any discharges of treated leachate comply with all relevant legislation. Whilst it is expected that complete elimination of unmanaged waste dumps that still persist in some countries will take several years to achieve, overall it is expected that the largest centres of waste production will be served by sites complying with the Landfill Directive.

Emissions of greenhouse gases from landfills takes place mainly in the form of methane, produced by the decomposition of biodegradable organic matter under the air-less conditions inside landfills. Methane emissions from landfills depend on the rate at which the gas is formed and on the extent to which it may be collected and flared or used for beneficial purposes. Formation rates vary markedly with waste composition and the design and operation of the landfill. In addition, the move away from small unmanaged dumpsites to larger sanitary landfills in some countries will increase the potential rates of methane formation. However, the reduction in biodegradable waste going to landfill and requirements for more effective gas control at landfills will reduce the longer term potential for methane emission. Estimates of methane emission from landfills are therefore subject to a wide range of uncertainty – probably at least a factor of two, from previous studies[24]. Given this uncertainty, we have used a constant rate of methane emission from MSW in landfills of 30 kg/tonne as a first approximation[24]. The analysis of externalities reported in Section 6 indicates that errors introduced from this source will have a very small impact on the overall environmental externalities assessed by the study.

In addition to methane, carbon dioxide is also emitted from the decomposition of organic matter in landfills. In the case of MSW, effectively all of the carbon dioxide comes from contemporary carbon sources, such as paper, food and vegetable remains and garden wastes and is therefore neutral in greenhouse gas terms. Fossil-derived carbon is present in non-biodegradable plastics and therefore is assumed to remain locked up in the landfill.

In the case of PVC, it appears that the resin itself is essentially non-biodegradable. However, plasticisers made from fossil carbon may leach out of the resin matrix into the landfill leachate. Plasticisers released into the leachate can be at least partially mineralised to carbon dioxide[2], whilst a proportion appears to bind strongly to colloidal organic matter and resist further decomposition. Long-chain phthalic acid esters, such as DEHP, appear to be more resistant to decomposition than shorter chain homologues. Estimating carbon dioxide emissions from this source is therefore subject to great uncertainty. For this study, we have assumed that half of the carbon in plasticiser (taken to be DEHP) is available for mineralisation and that half of this is converted to carbon dioxide. One tonne of DEHP containing 76 per cent carbon could therefore yield about 700 kg of CO_2. This is equivalent to about 200 kg of CO_2 per tonne of flexible PVC.

We must also consider the potential impact of additives on methane formation. The recent study on the behaviour of PVC in landfills reviewed this issue[2]. The authors reported that although phthalic acid esters (PAEs) may decompose to form methane in anaerobic bioreactors in the laboratory, there is little evidence to indicate significant decomposition to methane under real landfill conditions, or interference in methane formation from other wastes. Long chain PAEs, particularly DEHP, are especially resistant to decomposition. We have therefore assigned a methane emission factor of zero for all PVC components in landfills.

3.7 BURDENS FROM PVC RECYCLING

Energy requirements for processing polymers during mechanical recycling are fairly well characterised, since manufacturers of reprocessing equipment often provide data on energy consumption for various stages of the process (for example, washing, granulation etc.). Total energy demand for plastic recycling is typically in the range 10 to 15 MJ/kg, depending on the precise steps and their individual energy requirements[25]. For this study, we have adopted the lower value for low quality recycling and the upper value for high quality recycling. All of the energy is assumed to be consumed as electricity, equivalent to 2.78 and 4.17 MWh/tonne of PVC recycled.

There are also various other burdens associated with PVC recycling for which there is very little information. These include the use of ancillary reagents, such as detergents and flocculants used in the washing and cleaning process. There is also the question of emissions of volatile material during the heating, melting and blending stages, although these are thought to be relatively insignificant[26]. As an extreme example, maximum emissions of plasticiser from heating PVC plastisol coatings in hot-air ovens amount to be about 0.25-0.5%, although losses depend on the volatility of the plasticiser used. Many other volatile materials can also be present (for example, low molecular weight compounds from the stabiliser system, emulsifiers and viscosity depressants) that could bring the total losses from spread coating to about 2%. Clearly, the relatively enclosed heating/blending/melting operations in recycling would give rise to much lower emissions. Thus it is reasonable to assume that emissions from heating/blending/melting operations do not differ from emissions from similar operations in the production of virgin PVC compounds. There is also the issue of solid waste disposal from PVC recycling, which depends largely on the quality of the input reclaimed material. The waste is comprised of dirt, paper, glue, and traces of concrete and contamination by other polymers, and moisture. These wastes are not considered further in this study. Recovery rates of PVC entering recycling processes are generally high, about 95 per cent. The impact of losses of PVC during recycling have therefore been omitted.

3.8 BURDENS FROM PVC MANUFACTURE

High quality PVC recycling displaces the burdens of manufacturing an equivalent quantity of virgin material that the recyclate replaces. However, for low quality recycling, no virgin PVC manufacture is avoided since the recyclate produced from this operation does not take the place of new resin. Low quality recyclate may substitute for mixed plastic wastes or even wood or concrete, depending on the application to which it is put. Low quality recycling has not therefore been credited with any displaced burdens due to savings on the manufacture of new materials. As a result, the benefits for low quality recycling will be underestimated. Low quality recycling has been postulated to increase relative to BAU only under scenario 2 (see Table 7). In this scenario, about 5 per cent of recycled rigid PVC is expected to go for low quality recycling, whilst the corresponding figures for flexible formulations is about 46 per cent.. The omission of displaced burdens due to low quality recycling is therefore not thought to seriously undermine the analysis overall, although the impact will be greater for flexible formulations.

The burdens of PVC resin manufacture by a range of alternative processes have been estimated in a previous study[23] which also quantified inputs and outputs of the manufacture of sodium hydroxide as an additional product. The inputs and outputs for sodium hydroxide and PVC manufacture have been partitioned between the two products as described in the original report. Quite a wide range of emissions and energy usages are reported, which differ significantly between the manufacturing process. The report does, however, provide data based on emissions and burdens representation average EU plant and these are shown in Appendix 4. Key emissions to atmosphere are also shown in Table 16, below. Note that the data refer just to the production of PVC resin. Data on additives needed to blend with the resin to form PVC compound have not been included. This omission will result in an underestimation of PVC compound manufacture, particularly for flexible formulations that contain the largest proportion of components other than PVC resin.

Table 16 : Emissions to air from PVC manufacture, kg/tonne of resin.

Burden	Quantity
CO_2	1,944
NO_x	16
SO_2	13
Dust	3.9
HCl	0.23
Metals	0.003

3.9 BURDENS FROM TRANSPORT

Emissions from vehicles transporting waste, reagents and residues need to be taken into account in assessing the overall impact on environmental burdens associated with achieving the scenarios. Clearly, transport distances and modalities will vary markedly from country to country and for location to location, so any data chosen to represent groups of countries will be subject to considerable uncertainty. The following analysis has therefore been undertaken in order to scope the likely magnitude of transport burdens in relation to other impacts. We take as the starting point the key journeys and distances for the various transport elements (Table 17). All journeys are assumed to be by road transport using diesel-powered heavy goods vehicles.

Table 17: Transport distances used in the model

Journey	Distance, km
Local collection	25
Long haul transport to landfill	100
Long haul transport to recyclers	200
Reagents to incinerator	200
Residues from incinerator to landfill	100

We assume that wastes feeding an incinerator are collected within a radius of 25 km, typical of a major city, and delivered directly to the incinerator. We assume that lime and other reagents for pollution control at the incinerator would come from further away – say 200 km. Other wastes collected in the vicinity and destined for landfill would have a similar journey to a waste transfer station for onward transport to rural landfill – estimated at a further 100 km distance. A similar journey would be required for disposing of incinerator residues. PVC recycling facilities are currently thinly spread. With the growth in recycling, we estimate that local collection and delivery to a material recovery facility will be required (25 km) followed by transport to the recycling facility – at a further distance of 200 km. Local collection is assumed to be by means of a 5 tonne truck. All other journeys use a 30 tonne truck. The utilisation rate indicates the percent of time the vehicle is travelling fully laden. A 50 per cent utilisation indicates that the return journey is made empty.

Next, we need information on typical emissions per km.tonne for the selected transport mode. This information is given in Table 18, which relates to emissions typical of a 5 or 30 tonne truck. Also shown is the estimated cost of road traffic accidents that is included in the analysis of externalities.

Table 18: Vehicle emission factors and accident externalities (see reference 27)

Vehicle load	Utilisation	CO_2	NO_x	PM_{10}	SO_2	Accidents
			kg/tonne.km			€ /tonne.km
5 tonnes	50%	0.0857	0.000364	0.000245	0.0000269	0.02
30 tonnes	50%	0.0334	0.000183	0.000017	0.0000105	0.02

Emission factors in terms of kg pollutant emitted per tonne of material transported can now be determined for each of the main journeys (Table 19).

Table 19: Emissions and accident externalities kg or € /journey.tonne of material transported.

Journey	NO_x	SO_2	PM_{10}	CO_2	Accidents
		(kg /journey.tonne)			(€/journey.tonne)
Waste to incinerator	0.018	0.0013	0.012	4.3	1.0
Reagents to incinerator	0.073	0.0042	0.007	13.4	8.0
Residues to landfill	0.037	0.0021	0.003	6.7	4.0
Waste to landfill	0.055	0.0034	0.016	11.0	5.0
Waste to recyclers	0.092	0.0055	0.019	17.7	9.0

Burdens per tonne of waste, reagent or residues from each journey can now be calculated as the product of the weight of material transported and the factors shown in Table 19.

4 Scenario Analysis -Environmental Burdens

This Section summarises the environmental burdens per unit mass of PVC (rigid and flexible formulations) going to incineration, landfilling, recycling, and from virgin resin manufacture. The results are also presented in terms of cumulative changes, relative to BAU, resulting from the adoption of the three alternative scenarios of PVC waste management.

4.1 DIRECT BURDENS FROM INCINERATION

Direct emissions to the atmosphere from incineration of PVC and MSW are shown in Table 20. For those species governed by ELVs, the emitted quantities are simply the product of the ELV and air throughput per tonne of waste as outlined in Section 3.4.1. The amounts emitted are therefore independent of whether flexible or rigid PVC, or MSW is incinerated.

Table 20: Direct incinerator emissions to atmosphere at ELVs specified in the proposed Incineration Directive.

Species	Emission rate kg/tonne of waste incinerated (a)
Dust (PM_{10})	0.051
HCl	0.051
NO_x	1.012
SO_2	0.253(b)
Cd	0.00025
Pb	0.0025
Dioxins	0.506(a)

(a) Dioxins in ug I-TEQ/tonne. (b) Assumed to be zero for PVC.

Emission of fossil CO_2 is determined directly from the fossil carbon content of the waste (see Table 11 and Table 12 in Section 3.3). Similarly, the calorific value of the waste and the thermal efficiency of the incinerator determine energy recovered from incineration. We have assumed an overall thermal efficiency of 18 per cent for recovery of energy as electricity, typical of modern energy from waste plants. An equivalent amount of energy is assumed to be recovered as hot water or steam for district or process heating.

4.2 INDIRECT BURDENS FROM INCINERATION

Indirect emissions to atmosphere from incineration come from reagent manufacture, residue disposal and transportation. We will consider reagent manufacture first.

4.2.1 Reagent manufacture

The first stage in estimating burdens from APC reagent manufacture is to calculate the quantities of reagents required. This is done using the assumptions for the future pattern of emission control technology likely to be deployed over the next twenty years, as described in Section 3.4.2. The amount of reagent required for semi-dry and wet systems is estimated from the chlorine content of the waste (and sulphur content, in the case of MSW), the distribution of these elements within the incinerator and the amount released in stack gas and the stoichiometric factors shown in Appendix 3.

Reagent use varies markedly with the type of abatement system and reagent used. Table 21 shows the amount of reagent required per tonne of PVC or MSW for dry, semi-dry, semi-wet and wet APC systems which are considered in the analysis (APC reagent consumption is also shown for dry systems for completeness). The table assumes that PVC makes up half of the chlorine content of the average MSW referred to in Table 12. The last two rows of the table express the additional reagent demand in kg per tonne of rigid or flexible PVC. The detailed calculations are shown in Appendix 3. Wet systems have a lower reagent demand than semi-dry or wet systems. There is no difference in reagent demand between wet systems that discharge a liquid salts solution effluent and those that evaporate the salts solution to a dry residue for disposal on land (semi-wet wet systems). Wet systems that recover hydrogen chloride solution will not require alkaline reagents for HCl absorption. The right-most column shows the reagent demand for the estimated average APC plant mix assumed in the study.

Table 21: APC reagent consumption, kg/tonne of waste or added PVC

	Units	Dry lime	Dry bicarb	Semi dry lime	Wet	Semi-wet wet	APC average
System deployment		**0%**	**0%**	**25%**	**25%**	**50%**	
MSW free of PVC (Cl=3.19 kg/tonne)	kg/tonne of waste	10.19	9.32	9.50	4.06	4.06	5.42
MSW +PVC (Cl=6.38 kg/tonne)	kg/tonne of waste	16.83	17.23	15.15	7.68	7.68	9.55
Rigid PVC	kg/tonne of added PVC	1125	1342	958	615	615	700
Flexible PVC	kg/tonne of added PVC	703	838	598	384	384	438

Reagent requirement for the average mixture of APC plants outlined in Section 3.4.3 is shown in Table 22. It is evident from Table 21 and Table 22 that substantial savings in APC reagent requirements will come about by diverting PVC from incineration, even if this PVC is replaced at the incinerator by MSW.

Table 22: APC reagent consumption for average APC plant mix, kg/tonne of waste or PVC.

	MSW free of PVC	MSW+PVC	Rigid PVC	Flexible PVC
For chlorine				
Lime	1.95	4.73	472	295
NaOH	0.94	2.29	228	143
Total	2.89	7.02	700	438
For sulphur				
Lime	2.53	2.53		
NaOH	0.00	0.00		
Total for S	2.53	2.53		
Total for Cl and S	5.42	9.55	700	438

Having established the requirements for APC reagents, we can now express the burdens from the manufacture of these reagents on a *per tonne of waste* incinerated basis. Burdens from lime and sodium hydroxide manufacture *per tonne of reagent* shown in Table 15 and are multiplied by the reagent consumption rates for average APC plant mix given in Table 22. The results are shown in Table 23.

Table 23: Burdens from APC reagent manufacture – average APC plant mix, kg/tonne of waste or PVC.

	MSW free of PVC	MSW+PVC	Rigid PVC	Flexible PVC
Lime				
CO_2	4.48	7.26	472	295
NO_x	0.0008	0.0013	0.0849	0.0531
SO_2	0.012	0.019	1.255	0.784
NaOH				
CO_2	1.06	2.56	256	160
NO_x	0.007	0.016	1.645	1.027
Dust	0.003	0.007	0.71	0.44
SO_2	0.01	0.02	2.28	1.43
HCl	0.0001	0.0003	0.03	0.02
Metals	0.000002	0.000005	0.000457	0.000285

Data on metals and dust emissions from lime manufacture not available.

4.2.2 Residue disposal

Residues from incineration come from grate ash, fly ash and APC systems. We will deal with grate and fly ash from PVC incineration first. The quantities of these materials are calculated from the amount of inert solids in the waste (see Table 11 and Table 12). As explained in Section 3.4.3, inert residues from PVC incineration are assumed to be evenly distributed between grate ash and fly ash.

Table 24: Grate ash and fly ash for disposal from incineration, kg/tonne of waste

Residue	Rigid PVC	Flexible PVC	MSW
Grate ash(a)	6.6	21	120
Fly ash	16	52	24

(a) Assuming 60% of grate ash is recycled and so does not need disposal.

All of the fly ash and APC residues are assumed to be landfilled, but considerable use is made of incinerator grate ash as a construction material. Lead and cadmium in incinerator residues are shown in Table 25. The amounts were calculated from the distribution of elements in incinerator residues described in Section 3.4 and the estimated total concentration of the elements in PVC and MSW in Table 11 and Table 12.

Table 25: Metal burdens from incinerator residues, kg/tonne of waste.

Residue	Metal	Rigid PVC	Flexible PVC	MSW
Fly ash	Cadmium	0.08	0.05	0.006
	Lead	6.3	2.6	0.17
Grate ash (a)	Cadmium	0.017	0.01	0.0013
	Lead	10.7	4.5	0.29

(a) for disposal and recycling.

Residues of salts and excess APC reagents were calculated from the factors given in Appendix 3. The results for the various types of APC system considered are summarised in Table 26. Semi-dry and dry systems using lime as absorbent produce the greatest quantities of reagent for treatment and disposal, followed by dry systems using sodium bicarbonate. Overall, the lowest quantity of residue is produced by wet semi wet systems recovering hydrogen chloride solution and wet systems that discharge salts as a saline effluent. The residues produced by the assumed average APC plant mix are shown in the right most column. Further details are shown in Appendix 3.

Table 26: APC residues, kg/tonne of waste.

Residues	Units	Dry lime	Dry bicarb	Semi dry lime	Wet	Semi-wet wet	APC average
System deployment		**0%**	**0%**	**25%**	**25%**	**50%**	
MSW	kg/tonne of waste	14.30	6.89	13.64	2.58	7.63	7.87
MSW +PVC	kg/tonne of waste	24.19	12.39	22.57	2.58	13.73	13.15
Rigid PVC	kg/tonne of added PVC	1677	933	1515	0	1034	896
Flexible PVC	kg/tonne of added PVC	1048	583	946	0	646	559

Dry systems using lime and sodium bicarbonate are shown for completeness.

4.2.3 Transportation of waste, APC reagents and residues

Indirect burdens from incineration also include emissions from transporting waste and reagents to the incinerator and residue transportation to landfill. These burdens are calculated for the average mix of APC plant from the emissions per journey.tonne (Table 19) developed for the transport model described in Section 3.9, and the quantities of reagents and residues shown above (Table 27). Table 28 shows the total emissions (and damages from traffic accidents) from all transport routes involved with incineration. Burdens due to transportation of raw waste are the same, irrespective of whether PVC or MSW is carried, but those from reagent and residue transportation are much greater for PVC, in accordance with the greater quantities of reagents used and residues requiring disposal. Emissions from transportation are, however, small in comparison with the direct emissions from incinerator stacks, amounting to less than 10 per cent for the species considered.

Table 27: Burdens and accident externalities from waste, reagent and residue transport to/from incinerators for average APC plant mix, kg or € /tonne of waste.

	Raw waste to incinerator	Reagents			Residues for landfill (APC residues, fly and grate ash)		
		MSW	Rigid PVC	Flexible PVC	MSW	Rigid PVC	Flexible PVC
Material transported	1000	9.55	700	438	157	929	636
CO_2	4.288	0.128	9.354	5.853	1.052	6.209	4.253
PM_{10}	0.0123	0.0001	0.0048	0.0030	0.000535	0.0032	0.0022
NO_x	0.0182	0.0007	0.0513	0.0321	0.00577	0.0341	0.0233
SO_2	0.0013	0.0000	0.0029	0.0018	0.000330	0.0019	0.0013
Accidents	1.0	0.0764	5.6	3.504	0.630	3.717	2.546

(a) € /tonne.

Table 28 : Total transport burdens and accident externalities associated with incineration. Values are the sum of data in Table 27, kg or € /tonne of waste.

	MSW	Rigid PVC	Flexible PVC
CO_2	5.468	19.852	14.394
PM_{10}	0.01285	0.02017	0.01740
NO_x	0.02469	0.10364	0.07369
SO_2	0.00172	0.00623	0.00452
Accidents	1.706	10.317	7.050

(a) € /tonne.

4.3 BURDENS FROM LANDFILLING

Direct burdens associated with the landfilling of PVC wastes come principally from PVC resin, lead, cadmium and plasticisers in the PVC compound, and methane from MSW decomposition. These data have been presented previously in Section 3.3, but are repeated here for convenience (Table 29).

Table 29: Environmental burdens from landfilling, kg/tonne waste.

	Rigid PVC	Flexible PVC	MSW
PVC resin	949.6	592.7	-
Plasticiser	0	296.4	-
Lead	17.1	7.1	0.455
Cadmium	0.095	0.059	0.0072
CO_2 from plasticisers	-	206	-
Methane emission	-	-	30

The main indirect burden from landfilling quantified in this study is from transportation of waste to the landfill. These burdens have already been presented in Table 19.

Table 30: Burdens from waste transport to landfill.

Burden (a)	**Value**
CO_2	10.970
PM_{10}	0.0157
NO_x	0.0549
SO_2	0.0034
Accidents	5.0

(a) All expressed in kg/tonne, except accidents, which are in € /tonne.

Burdens from transporting waste to landfills are greater than for transportation involved with MSW incineration, because of the greater distances assumed for direct landfilling of raw wastes. However, transportation burdens to landfill are less than those of incineration of PVC, because of the need in the latter case to transport and dispose of much larger amounts of reagents and residues, compared with MSW.

4.4 BURDENS FROM RECYCLING

The quantified burdens related to recycling in this study relate to energy use for reprocessing and transportation to the recycling facility. These burdens are summarised in Table 31, which draws on data presented in Section 3.7 and Table 19. No distinction is made between rigid and flexible formulations.

Table 31: Burdens and energy use from PVC recycling.

Burden	Units	Value
Energy, high quality recycling	MWh/tonne	4.17
Energy, low quality recycling	MWh/tonne	2.78
Transportation		
CO_2	kg/tonne	17.65
PM_{10}	kg/tonne	0.01905
NO_x	kg/tonne	0.09157
SO_2	kg/tonne	0.00554
Accidents	€ /tonne	9.0

4.5 BURDENS FROM PVC RESIN MANUFACTURE

Principal environmental burdens associated with PVC resin manufacture that are displaced by high quality recycling are shown in Table 32, based on information shown in Appendix 4.

Table 32: Burdens from PVC manufacture, kg/tonne of compound.

Burden	Rigid PVC	Flexible PVC
CO_2	1,846	1,152
Dust	3.70	2.31
SO_2	12.34	7.71
NO_x	15.19	9.48
HCl	0.22	0.14
Metals	0.0028	0.0018

4.6 OVERALL ENVIRONMENTAL BURDENS FROM PVC WASTE MANAGEMENT

This Section brings together the environmental burdens calculated above and expresses them in terms of unit mass (tonnes) of rigid or flexible PVC processed. Comparative data for MSW is also shown. Burdens from incineration are shown in Table 33, from landfilling in Table 34, from recycling in Table 35 and from manufacture of virgin resin in Table 36.

In addition, data relating to the principal emissions to the atmosphere featuring in the environmental analysis undertaken in section 6 (greenhouse gases, NO_x , SO_2 and PM_{10})are also shown as bar charts (Figure 8 to Figure 11) and solid residues for disposal (Figure 12.)

Table 33: Environmental burdens from incineration (average APC plant mix).

Incineration burdens	Units	Rigid PVC	Flexible PVC	MSW
Direct emissions to air				
CO_2	kg / tonne of waste	1393	1673	264
PM_{10}	kg / tonne of waste	0.051	0.051	0.051
NO_x	kg / tonne of waste	1.01	1.01	1.01
SO_2	kg / tonne of waste			0.25
HCl	kg / tonne of waste	0.051	0.051	0.051
Cd	kg / tonne of waste	0.00025	0.00025	0.00025
Pb	kg / tonne of waste	0.0025	0.0025	0.0025
Dioxin	ug I-TEQ / tonne of waste	0.51	0.51	0.51
Other direct burdens				
Electricity generated	MWh / tonne of waste	0.81	1.00	0.50
Heat generated	MWh / tonne of waste	0.81	1.00	0.50
Indirect emissions to air				
APC reagent manufacture				
CO_2	kg / tonne of waste	728.00	455.00	9.82
Dust	kg / tonne of waste	0.71000	0.44000	0.00700
NO_x	kg / tonne of waste	1.73000	1.08000	0.01700
SO_2	kg / tonne of waste	3.54000	2.21400	0.03900
metals	kg / tonne of waste	0.00050	0.00030	0.00001
HCl	kg / tonne of waste	0.03000	0.02000	0.00030
Transportation of waste, reagents and residues				
CO_2	kg / tonne of waste	19.85	14.39	5.47
PM_{10}	kg / tonne of waste	0.020	0.017	0.013
NO_x	kg / tonne of waste	0.104	0.074	0.025
SO_2	kg / tonne of waste	0.006	0.005	0.002
Accidents	€ / tonne of waste	10.317	7.050	1.706
APC reagents required				
Lime	kg / tonne of waste	472	295	7.26
Sodium hydroxide	kg / tonne of waste	228	143	2.29
APC reagent (NaOH) resource use				
Fuels & feedstock (a)	GJ / tonne of waste	4.73	2.96	0.05
Water use	kg / tonne of waste	1208	757	12.10
Other raw materials	kg / tonne of waste	134	84.4	1.35
Solid residues to landfill				
APC residues	kg / tonne of waste	896	559	13.15
Grate ash (excluding amount recycled)	kg / tonne of waste	6.60	21.00	120
Fly ash	kg / tonne of waste	16.0	52.0	24.0
Solid wastes from NaOH mnfr	kg / tonne of waste	16.90	10.60	0.17
Cadmium in incinerator residues	kg / tonne of waste	0.09	0.05	0.01
Lead in incinerator residues	kg / tonne of waste	10.58	4.40	0.29
Other burdens from NaOH mnfr				
Water emissions	kg / tonne of waste	8.80	5.52	0.09

(a) Emissions associated with fuel and feedstock use for NaOH included under Indirect emissions to air: APC reagent manufacture.

Table 34: Environmental burdens from landfilling.

Burdens from landfilling	Units	Rigid PVC	Flexible PVC	MSW
Wastes to landfill				
Total waste landfilled	kg / tonne of waste	1000	1000	1000
PVC resin	kg / tonne of waste	949.6	592.7	
Plasticiser in PVC compound	kg / tonne of waste		296.4	
Cadmium in PVC compound	kg / tonne of waste	0.10	0.06	0.01
Lead in PVC compound	kg / tonne of waste	17.10	7.10	0.46
Direct emissions to air				
Methane emission	kg / tonne of waste			30.00
CO2 from plasticiser	kg / tonne of waste		206.49	
Indirect burdens - transportation				
CO_2	kg / tonne of waste	10.970	10.970	10.970
PM_{10}	kg / tonne of waste	0.016	0.016	0.016
NO_x	kg / tonne of waste	0.055	0.055	0.055
SO_2	kg / tonne of waste	0.003	0.003	0.003
Accidents	€ / tonne of waste	5.000	5.000	5.000

Table 35: Environmental burdens from recycling.

Burdens from recycling	Units	Rigid PVC	Flexible PVC
Energy			
For high quality recycling	MWh/tonne of waste	4.17	4.17
For low quality recycling	MWh/tonne of waste	2.78	2.78
Transportation of waste to recycling			
CO_2	kg / tonne of waste	17.6517	17.6517
PM_{10}	kg / tonne of waste	0.0191	0.0191
NO_x	kg / tonne of waste	0.0916	0.0916
SO_2	kg / tonne of waste	0.0055	0.0055
Accidents	€ / tonne of waste	9.0000	9.0000

Table 36: Environmental burdens from PVC resin manufacture.

Burdens from virgin PVC resin manufacture	Units	Rigid PVC	Flexible PVC
PVC resin content	kg / tonne of compound	950	593
Direct emissions to air			
CO_2	kg / tonne of compound	1846	1152
Dust	kg / tonne of compound	3.70	2.31
NO_x	kg / tonne of compound	15.19	9.48
SO_2	kg / tonne of compound	12.34	7.71
Metals	kg / tonne of compound	0.0028	0.0018
HCl	kg / tonne of compound	0.22	0.14
Other burdens from PVC mnfr			
Fuels & feedstock (a)	GJ/tonne of compound	63.44	39.60
Water use	kg / tonne of compound	18,042	11,261
Other raw materials	kg / tonne of compound	658	411
Water emissions	kg / tonne of compound	49.2	30.7
Solid wastes	kg / tonne of compound	123	77.1

(a) Emissions associated with fuel and feedstock use for PVC manufacture are included with 'direct emissions to air.'.

Figure 8: Greenhouse gas emissions from PVC waste management and resin manufacture, kg/tonne of compound or MSW.

Figures relate principally to CO_2 emissions, but include CH_4 from landfilled MSW. The global warming potential (GWP) is usually taken to be 21 times that of CO_2 over a 100 year timeframe.

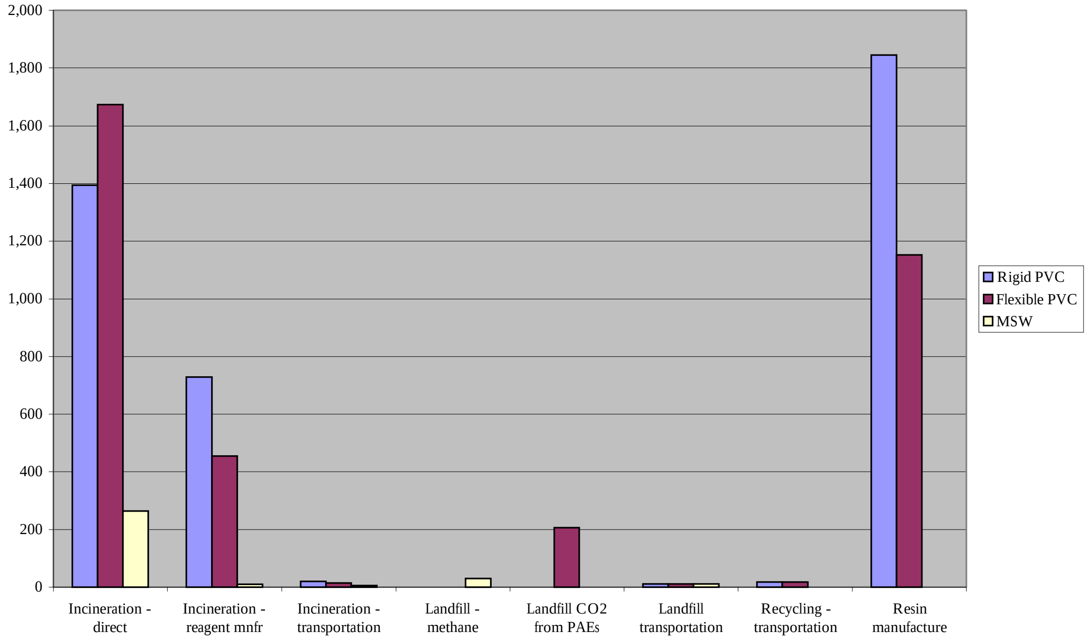


Figure 9: NO_x emissions from PVC waste management and resin manufacture, kg/tonne of compound or MSW.

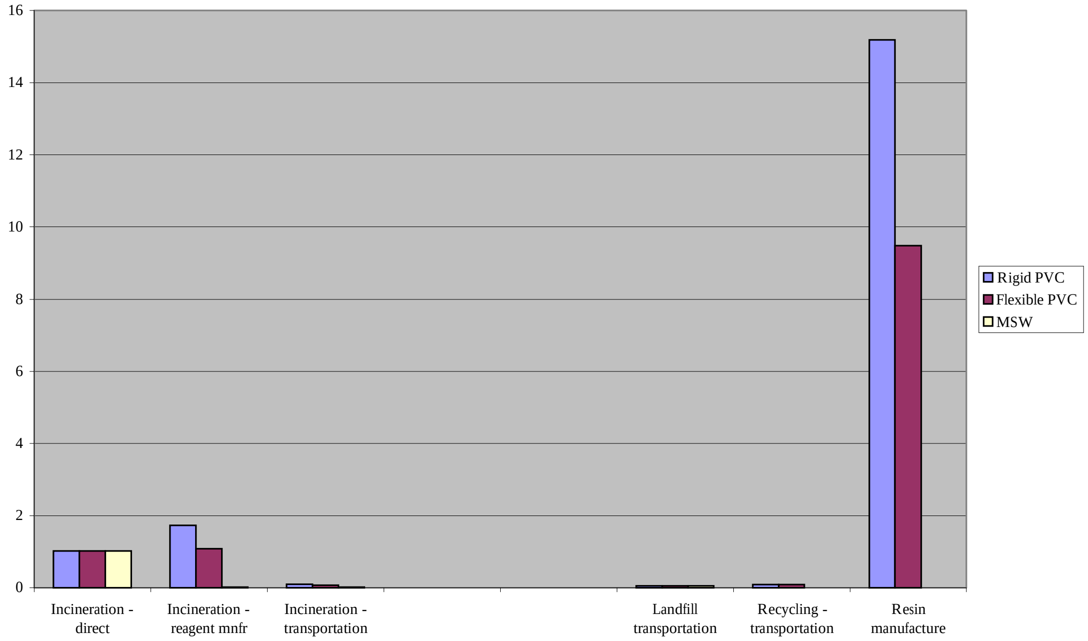


Figure 10: SO2 emissions from PVC waste management and resin manufacture, kg/tonne of compound or MSW.

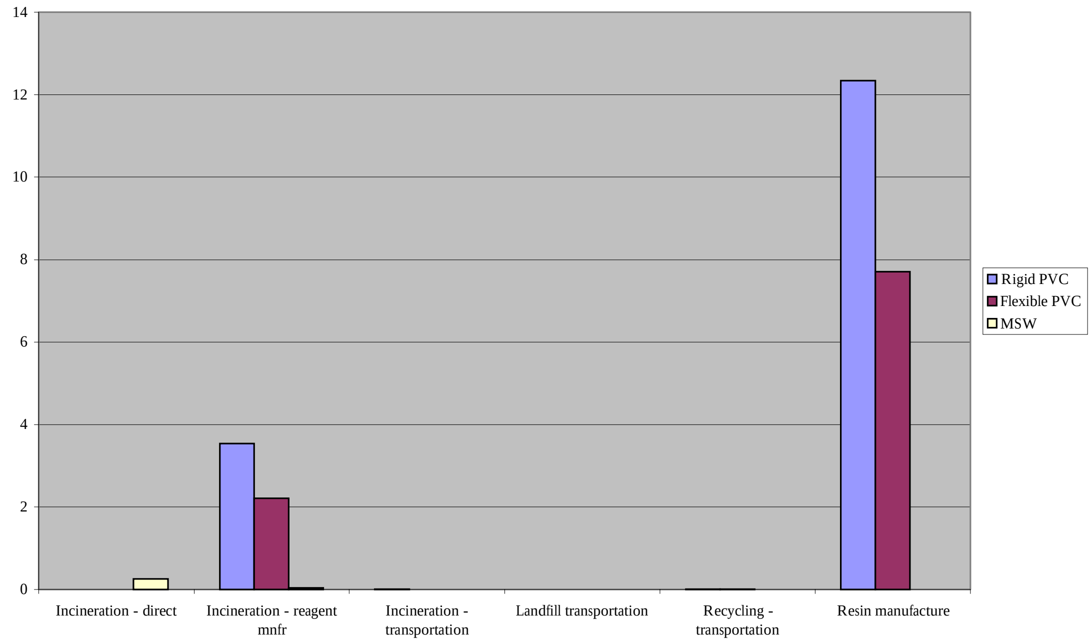


Figure 11: Dust emissions from PVC waste management and resin manufacture, kg/tonne of compound or MSW. Taken to be entirely PM_{10} .

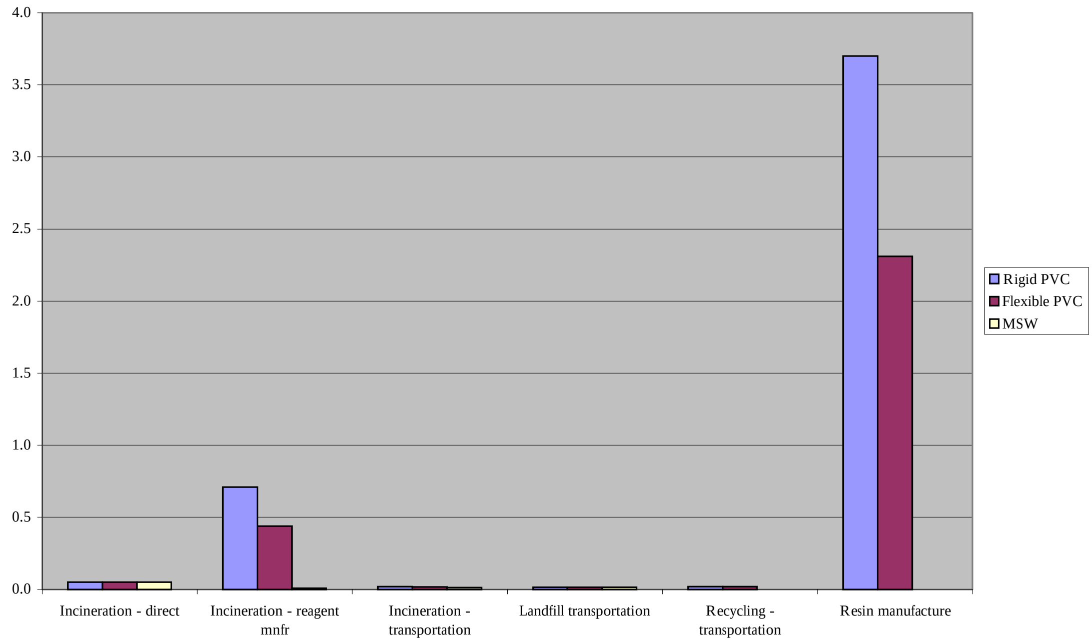
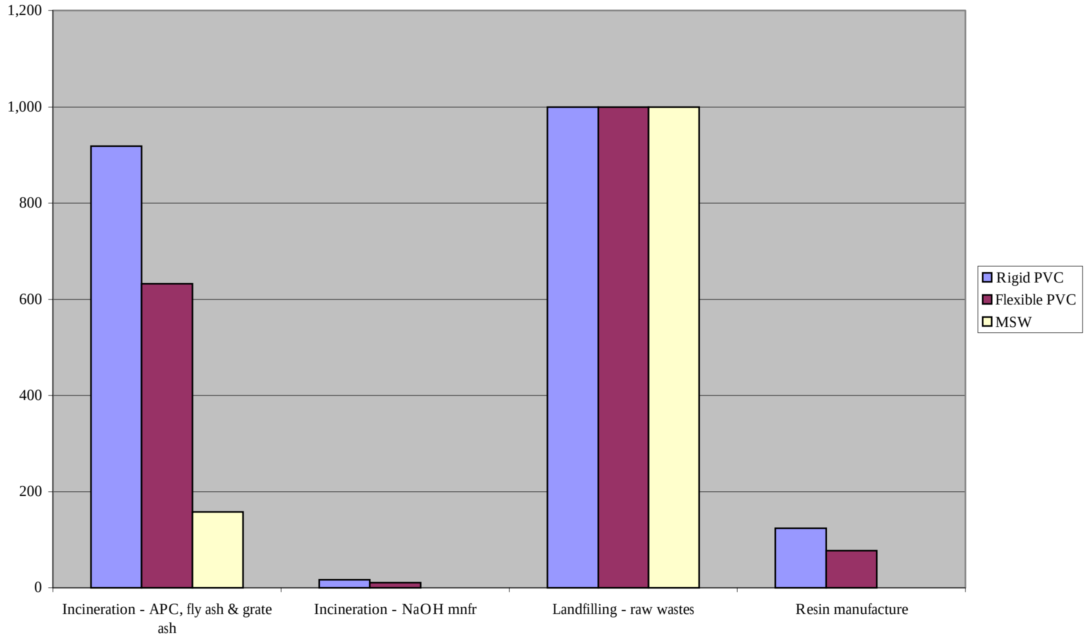


Figure 12: Solid residues from PVC waste management and manufacture. Average incineration APC plant mix. kg/tonne.



The following conclusions may be drawn from the environmental burdens summarised from the above results:

- Comparative data on greenhouse gas emissions are shown in Figure 8. The largest source of carbon dioxide emissions in the system considered is PVC manufacture (Table 36), accounting for just over 1,800 kg / tonne of rigid PVC compound. A smaller quantity (almost 1,200 kg / tonne) is attributed to flexible PVC formulations. The burdens from PVC manufacture relate only to the resin itself and do not include impacts from additives. As a result, burdens calculated from this source will underestimate the benefits of avoided manufacture. This will affect estimates for flexible PVC more severely because a greater proportion of flexible formulations is made up of additives, especially plasticisers.

- The next largest source of carbon dioxide is direct emissions from incineration of PVC (Table 33), producing about 1,400 to 1,700 kg / tonne. This compares with under 300 kg / tonne for MSW. A further 400 – 700 kg / tonne is produced indirectly in making the reagents needed to abate acid gas emissions (compared with less than 10 kg/tonne for reagents needed for MSW incineration). Emissions from transportation of waste, reagents and residues are small (less than 20 kg/tonne) in comparison. Taken together, direct and indirect emissions of carbon dioxide from incineration are therefore comparable with the emissions from resin manufacture. Electricity generation at incinerators also affects net greenhouse (and other) gas emissions by displacing emissions from other generating sources. These displaced emissions are taken into account in the externality analysis.

- Landfilling PVC also has an impact on greenhouse gas emissions (Table 34). These burdens come from emission of fossil carbon dioxide from plasticiser degradation (206 kg / tonne). Some 30 kg / tonne for methane emissions is attributed to MSW.

When PVC is diverted from incineration, its place may be taken by MSW that would otherwise have been landfilled, so reducing methane emissions from this source.

- Recycling (Table 35) makes a small contribution to carbon dioxide emissions through the energy used in processing and emissions from transportation of PVC to the recycling centres.

- The largest source of nitrogen oxides, sulphur dioxide, dust (taken to be entirely PM_{10}) is PVC manufacture. Manufacture produces over ten times as much NO_x as originates in direct emissions from incinerators and over eight times as much from APC reagent manufacture. About four times as much SO_2 is produced by PVC manufacture as for APC reagent manufacture (no SO_2 is assumed to come from the direct incineration of PVC. Manufacture is also the dominant source of dust and metal emissions in the system under study. Manufacturing produces over ten times as much NO_x as originates from direct emissions from incineration and over eight times as much from APC reagent manufacture. About four times as much SO_2 is produced by PVC manufacture as for APC reagent manufacture (no SO_2 is assumed to come from PVC incineration). PVC manufacture is also the dominant source of dust (PM_{10}) and metal emissions.

- In terms of emissions to atmosphere, therefore, the greatest reduction in burdens will originate from displacing burdens from PVC manufacture through high quality recycling. Burdens reduction at the incinerator and in the manufacture of APC reagents has a significantly smaller impact. Because of this, the impacts of whether PVC diverted from incineration is replaced by MSW on either a mass or heat equivalence basis (or indeed at all) has a small impact on the overall environmental burdens.

- Incineration using estimated average APC plant mix of rigid PVC requires over 70 times as much APC reagents to control acid gas emissions as MSW. Flexible formulations require about 45 times as much as MSW. The actual amount depends on the type of APC system employed.

- In terms of disposal of residues to land, the greatest quantity is produced by PVC incineration. In the case of rigid PVC, the total mass of residues requiring disposal is about 92 per cent of the original mass of waste incinerated, whilst flexible formulations produce a residue amounting to about 63 per cent by mass of the incinerated waste. These estimates are based on average APC plant mix. Residue disposal will be significantly higher for dry and semi-dry systems and least for wet systems or those recovering hydrogen chloride or salts for sale.

- Incineration converts bound lead and cadmium into potentially more mobile inorganic forms for landfilling in the residues. Incineration is usually justified as a means of reducing the amount of waste requiring ultimate disposal and converting it to a less hazardous form. As far as rigid PVC is concerned, these criteria are clearly not achieved. Incineration does, however, effectively destroy plasticisers in flexible formulations and so could be justified over direct landfilling if the risks posed by plasticisers in landfills are judged to be sufficiently large.

4.7 IMPACTS OF INCREASED RECYCLING ON ENVIRONMENTAL BURDENS

Having quantified the environmental burdens per tonne of PVC waste managed, we can now calculate the overall impacts of diverting waste from incineration or landfilling to recycling. The diversion routes of interest to us are:

		Diversion route	Relevant scenarios
Incineration	➔	High quality recycling	Scenario 1 and 2
Landfill	➔	High quality recycling	Scenario 1 and 2
Incineration	➔	Low quality recycling	Scenario 1 and 2
Landfill	➔	Low quality recycling	Scenario 1 and 2
Incineration	➔	Landfill	Scenario 3

Details of the burdens avoided by each of these diversion routes are summarised in Appendix 5, for rigid and flexible PVC. The burdens for the diversion rates were calculated from the sum of the burdens and avoided burdens from each of the relevant waste management options. For example, the burdens from diverting PVC from incineration to high quality recycling were calculated as the burdens for recycling, plus the *avoided* burdens from manufacture and incineration. The overall results from this part of the analysis are shown visually in Table 37, which gives a qualitative indication of the main environmental burdens abated by each diversion route. Details are given in Appendix 5.

Table 37 : Qualitative assessment of diversion routes for PVC waste.

Diversion route	Air emissions		Discharges to land	
	CO_2	NO_x , SO_2, PM_{10} metals	Solid residues	Other
Incineration to high quality recycling	☺☺☺☺	☺☺☺☺	☺☺☺☺	
Landfill to high quality recycling	☺☺	☺☺☺☺	☺	Plasticiser (a) ☺☺☺☺ Raw waste ☺☺☺☺
Incineration to low quality recycling (b)	☺☺	☺	☺☺☺	
Landfill to low quality recycling (b)	😐	😐	😐	Plasticiser (a) ☺☺☺☺ Raw waste ☺☺☺☺
Incineration to landfill	☺☺	😐	☺☺☺☺	Plasticiser ☹☹☹☹ Raw waste ☹☹☹☹

Key: ☺ = beneficial change, 😐 = neutral, ☹ = detrimental change. The more ☺ (or ☹) symbols shown, the better (or worse) is the diversion option. (a) Burdens due to plasticiser affect flexible PVC only. (b) Low quality recycling is not credited with avoided burdens from PVC manufacture since virgin resin would not be used for the same applications as low quality recyclate.

The main conclusions regarding the relative environmental benefits of each of the diversion rates are summarised as follows:

- Diversion from incineration to high quality recycling offers the greatest overall reduction in CO_2, other air pollutants and discharges to land.

- Diversion from incineration to low quality recycling (in which no replacement of virgin resin manufacture takes place) achieves a smaller reduction in solid residues, about half the CO_2 and considerably less reduction in other air pollutants.

- Diversion from landfill to high quality recycling scores well for reduction in air pollutants, raw wastes to landfill and (for flexible PVC) reducing plasticisers going to landfill[m].

- Diversion from landfill to low quality recycling (which is not credited with the avoided burdens of PVC manufacture) scores highly only in reducing raw waste and plasticiser to landfill.

- Diversion from incineration to landfill scores highly in reducing residues for disposal (which require disposal as hazardous waste) but conversely, does badly in terms of increasing raw waste and plasticisers (for flexible PVC) going to landfill.

Having established the role of the various diversion rates, we can now assemble their relative contributions and evaluate the waste management scenarios.

4.8 OVERALL BURDENS FROM THE SCENARIOS

Having established the burdens per tonne for each waste management option for rigid and flexible PVC, we can now assemble the results to determine the total cumulative change in burdens in achieving the scenarios, compared with the BAU case. To do this, we multiply the burdens per tonne for each diversion route given in Appendix 5 by the total quantity of PVC following each route (shown in Table 7 in 2.5.2). The detailed results of these calculations are reported in Appendix 6. These results for the principal burdens are summarised in Table 38:

[m] The issue of whether it is preferable for plasticisers and other additives to be disposed of in landfills or dispersed into products made from recycled PVC is beyond the remit of the present study.

Table 38: Principal burdens of the scenarios (rigid and flexible PVC).

Scenario	Incineration future	CO_2 ktonnes	NO_x ktonnes	SO_2 ktonnes	PM_{10} ktonnes	Electricity TWh	Methane	Accidents million €	APC reagents ktonnes	Solid residues ktonnes
1	High	-11,436	-69	-58	-17	19	-49	4	-1,209	-1,924
	Low	-10,998	-68	-58	-17	19	-43	5	-1,054	-1,745
	Mean	**-11,217**	**-69**	**-58**	**-17**	**19**	**-46**	**5**	**-1,132**	**-1,834**
2	High	-21,295	-116	-100	-29	40	-112	10	-2,451	-3,703
	Low	-20,345	-115	-98	-29	40	-97	13	-2,137	-3,343
	Mean	**-20,820**	**-116**	**-99**	**-29**	**40**	**-105**	**12**	**-2,294**	**-3,523**
3	High	-19,384	-16	-27	-6	5	-315	-72	-5,901	-6,749
	Low	-16,772	-14	-24	-5	4	-272	-62	-5,108	-5,843
	Mean	**-18,078**	**-15**	**-25**	**-6**	**5**	**-294**	**-67**	**-5,504**	**-6,296**

Shaded values are used in the analysis of environmental externalities. The results presented are the average burdens when PVC is either not replaced at the incinerator, or replaced by MSW on a mass or heat equivalent basis. Full details are given in Appendix 6.

The main conclusions from this analysis are:

- For carbon dioxide emissions, scenario 2 achieves the greatest reduction (~21 Mtonnes), compared with about 11 Mtonnes for scenario 1 and about 18 Mtonnes for scenario 3. Scenarios 1 and 2 benefit from reductions in emissions from PVC manufacture that are avoided by high quality recycling, whereas scenario three has no increase in recycling above BAU rates.

- Savings in methane emissions result from MSW that would have been landfilled replacing the PVC diverted from incineration. Scenario 3 shows the greatest reductions in methane emissions, reflecting the diversion of PVC from incineration directly to landfill under this scenario.

- Scenario 2 also achieves the greatest reduction in NO_x burdens (~116 ktonnes), again due in part to displaced emissions from manufacture. Burdens for scenario 1 are about 70 ktonnes and scenario 3 about 15 ktonnes. A similar pattern is seen for SO_2 and PM_{10}.

- Scenario 2 increases electricity demand by about 40 TWh, due to the needs of recycling and the loss of generation at the incinerators. Scenario 1 increases electricity demand by about 19 TWh, and Scenario 3 by about 5 TWh. In the latter case, this is accounted for by lost electricity from incineration, since recycling does not play a role in this instance. Note that electricity used for manufacture of PVC has not been separately calculated since the relevant externalities have been included already in the burdens of PVC manufacture.

- Scenario 3 reduces the requirements for APC reagents by about 5.5 Mtonnes, compared with about 2.3 Mtonnes in scenario 2 and ~1.1 Mtonnes in scenario 1. Reagent use is directly proportional to PVC incineration rates.

- Solid residue requiring disposal decreases by ~6.3 Mtonnes in scenario 3, by about 3.5 Mtonnes in scenario 2 and by about 1.8 Mtonnes in scenario 1.

We will now consider the financial costs of the scenarios.

5 Financial analysis

5.1 APPROACH

The purpose of this part of the study is to estimate the financial costs resulting from the implementation of the scenarios developed in Section 2.5.2 from a *waste management* perspective – in particular, the costs of diverting post-consumer PVC away from incineration and landfilling and towards mechanical recycling. Issues related to the substitution of PVC by other materials and those concerning the use of recycled PVC instead of virgin resin are therefore excluded. Similarly, the analysis excludes consideration of possible effects on trade and employment due to mechanical recycling displacing virgin PVC manufacture, since the quantities going for recycling make up a very small proportion of virgin resin output.

To reiterate a key point established in Section 2.4.1, current mechanical recycling rates for post-consumer PVC wastes are very low because the costs of disposing of the waste to landfill or incineration, as paid by the waste producer, is less than the net cost of recycling. Stimulating recycling for most of these wastes will therefore require some form of 'subsidy' – i.e. additional costs to be paid by industry, waste owners or society as a whole, depending on the model adopted, to redress the market advantage enjoyed by disposal options over recycling. However, when PVC is sent for incineration, producers of the PVC waste pay a 'subsidised' rate for disposal. This is because the costs of incineration of one tonne of PVC are substantially higher than for the same quantity of MSW, yet this difference is not reflected in the disposal fee. In effect the producer of PVC waste benefits from a subsidised fee for incineration, the additional cost being paid indirectly by all waste producers using the facility. The overall impact of PVC at current concentrations in the MSW stream is slight, in terms of increased incinerator running costs expressed *per unit of total waste incinerated*, but substantial when expressed in terms of *PVC throughput*. These issues are further elaborated upon below. If this additional cost on PVC incineration could be internalised within the disposal fee, then the present cost advantage of incineration over recycling would be reversed for some PVC wastes. The cost of any proposed measures to stimulate PVC recycling must therefore take account of this 'incineration subsidy' that would be avoided by diverting PVC away from incineration.

The cost elements of interest in estimating the waste management costs of the scenarios are summarised in Table 39. The table is divided into *avoided* costs (top) resulting from diversion of PVC waste, and *incurred* costs (bottom). The overall cost of the diversion is the sum of avoided and incurred costs. The cost elements identified in the table are quantified in the following paragraphs.

Table 39: Waste management cost elements considered in the analysis.

Scenarios 1 and 2		Scenario 3
Incineration ➔ Recycling	**Landfill ➔ Recycling**	**Incineration ➔ Landfill**
Avoided costs		
➢ Incinerator 'subsidy' ➢ Incinerator charges	➢ Landfill charges	➢ Incinerator 'subsidy' ➢ Incinerator charges
Incurred costs		
➢ Recycling cost	➢ Recycling cost	➢ Costs of additional sorting ➢ Landfill charges
Net costs		
➢ Sum of avoided and incurred costs		

5.1.1 'Incinerator subsidy'

The value of the 'subsidy' for PVC incineration relates principally to the additional costs of reagent for controlling emissions of hydrogen chloride and the treatment and disposal of the residues so produced, compared with MSW that does not contain PVC. In addition, the value of the energy recovered (as heat and/or electricity) is greater when PVC is incinerated, because of its higher calorific value compared with MSW, and this impact must also be included. Because APC equipment is required to meet emission limits irrespective of whether or not PVC is present in the incinerator waste stream, there are no significant implications for the capacity of the APC plants related to the presence of PVC and so there are no significant impacts on capital costs. Similarly, no additional investment is required that can be attributed to processing PVC in the waste stream at the current low levels of occurrence. There are also considered to be no additional labour or maintenance costs attributable to PVC incineration with MSW[3].

The costs of gas treatment (including energy recovery) for MSW and PVC waste have been quantified by the Bertin study on PVC incineration for several designs of gas treatment system. Their methodology and cost estimates for reagents, disposal and energy revenues have been adopted in this study, using the factors for reagents and residue in Appendix 3. Cost element values are given in Table 40.

Table 40: Cost elements for APC reagents, residue disposal and energy sales from MSW or PVC incineration - see reference 3 for details.

Item	Price €/tonne	Comment
APC reagents: Lime Sodium bicarbonate Sodium hydroxide	 74.5 191 142.8	 Average of 6 plants Average of 2 plants Average of 5 plants
Residue disposal: without stabilisation with stabilisation	 105 175	Average of at least 17 plants
Heat and electricity sales MSW PVC energy sales value calculated in this study in proportion to calorific values of PVC compound given in Table 11.	-18.5 €/tonne of MSW -30 €/tonne rigid PVC -37 €/tonne flexible PVC	Based on steam/electricity prices and conversion efficiency.

Table 41 shows the overall costs of reagent, residue disposal and energy sales when PVC contributes 50 per cent of the chlorine to the average MSW composition used in this study. As a result, the chlorine content of the waste increases from 3.19 kg/tonne without PVC to 6.38 kg/tonne with it. This quantity of chlorine could be provided by some 5.89 kg of rigid PVC per tonne of MSW or 9.44 kg of flexible compound of the composition shown in Table 11. We can therefore calculate the additional costs associated with the presence of rigid or flexible PVC.

Table 41: Costs due to PVC in MSW. Units are in €/tonne MSW or PVC incinerated.

	Dry lime	Dry bicarb	Semi dry lime	Wet	Semi-wet wet	APC average
APC plant mix	**0%**	**0%**	**25%**	**25%**	**50%**	
APC REAGENTS						
Cost for MSW free of PVC / tonne of MSW	**0.76**	**1.78**	**0.71**	**0.39**	**0.39**	**0.47**
Cost for MSW with PVC / tonne of MSW	1.25	3.30	1.13	0.78	0.78	0.87
Increase due to PVC / tonne of MSW	0.49	1.51	0.42	0.39	0.39	0.40
Cost increase /tonne rigid PVC	**83.8**	**256.7**	**71.3**	**66.6**	**66.6**	**67.8**
Cost increase /tonne flexible PVC	**52.4**	**160.4**	**44.6**	**41.6**	**41.6**	**42.3**
APC RESIDUE DISPOSAL						
MSW free of PVC - without residue stabilisation	1.50	0.72	1.43	0.27	0.80	0.83
MSW free of PVC - with residue stabilisation	2.50	1.21	2.39	0.45	1.34	1.38
MSW free of PVC – average	**2.00**	**0.96**	**1.91**	**0.36**	**1.07**	**1.10**
MSW – without residue stabilisation	2.54	1.30	2.37	0.27	1.44	1.38
MSW - with residue stabilisation	4.23	2.17	3.95	0.45	2.40	2.30
MSW – average	3.39	1.73	3.16	0.36	1.92	1.84
Increase due to PVC	1.38	0.77	1.25	0.00	0.85	0.74
Cost increase/tonne rigid PVC	***235***	***131***	***212***	***0***	***145***	***126***
Cost increase/tonne flexible PVC	***147***	***82***	***132***	***0***	***90***	***78***
ENERGY SALES						
MSW free of PVC	-18.5					
Rigid PVC	-30.0					
Flexible PVC	-37					
TOTAL COSTS						
MSW free of PVC / tonne of MSW	**-15.74**	**-15.75**	**-15.88**	**-17.75**	**-17.04**	**-16.93**
Rigid PVC / tonne of PVC	**289.0**	**357.8**	**253.8**	**36.7**	**181.6**	**163.4**
Flexible PVC / tonne of PVC	**162.0**	**204.9**	**140.0**	**4.6**	**95.0**	**83.7**

The costs for APC reagents and residue disposal per tonne of MSW (free of PVC and with PVC) have been calculated from the total amounts of APC reagents and residues given in Appendix 3 ('Overall reagent consumption and residue production') and the unit costs of reagents and residue treatment and disposal shown in Table 40. The increase due to PVC in the MSW is thence obtained by subtracting the costs per tonne of MSW free of PVC from those of MSW with PVC. This increase in cost can then be expressed in terms of € per tonne of PVC by dividing by the amount of PVC that contributes the additional chlorine – i.e. 5.89 kg of rigid PVC, or 9.44 kg of flexible PVC, per tonne of MSW

The last three lines of the table show the total costs of incinerating MSW free of PVC (€ /tonne of MSW) and rigid or flexible PVC (€ / tonne of PVC). The total costs are the sum of reagent costs, residue treatment and disposal costs *less* energy sales income.

The results indicate that for the estimated average mix of APC plant, net costs of PVC incineration (i.e. the 'incineration subsidy', shown in the last two lines of the table) are about € 165/tonne for rigid and about € 85/tonne for flexible PVC, including the value of energy sales. On the same basis, reagent and residue costs for MSW, net of energy sales, are about –€ 17/tonne. Costs for PVC vary markedly according to the type of APC system, with highest costs for dry systems and lowest for wet, where salts are discharged as saline effluent.

5.1.2 Landfill and incineration charges

Comprehensive information on the financial and economic costs of various waste management options has been compiled for the Commission in a previous study by Coopers & Lybrand/CSERGE in 1996, relating to the then EU-12 countries[28]. The study compares costs for 31 waste management options (such as collection, transfer, reprocessing, landfill, incineration etc), combined together as seven waste management systems. Of particular relevance to the present study are the landfill and incineration systems.

The landfill system evaluated by Coopers and Lybrand/CSERGE encompasses costs of mixed waste collection and disposal in urban landfills and collection, followed by transfer, before disposal in rural landfills. The incineration system considers mixed waste collection and either direct delivery of waste to an urban incinerator or incineration after intermediate transfer. Incinerators are assumed to recover energy and residues are disposed of, after transfer, in rural landfills for hazardous wastes. Base case economic costs in 1999 money (averaged for EU-21) for the two waste management systems were determined as:

Landfill system:	€ 100 /tonne[n]
Incineration system	€ 165 / tonne.

Variation between member states around these averages is about +/- 25 per cent, with landfill and incineration costs being generally well correlated. Costs are highest in Denmark, the Netherlands and Germany and lowest in Greece, Spain and Portugal. There is also considerable variation within countries, and overlap between the costs of competing waste management systems is seen.

In scenario 3, diversion of PVC in constructional applications is diverted from incineration to landfill. The PVC waste management system must therefore bear the cost of this additional segregation step. However, increasing segregation of non-masonry construction waste is

[n] The study authors' quote € 95.3 / tonne for the landfill system and € 156.1 for the incineration system, in 1993 money. The values in 1999 money were obtained by inflating according to the total industry industrial producer price index, published by Eurostat. In the landfill waste management system, waste collection and transfer costs make up about 70 to 80 per cent of the total cost of the system, the remainder being the cost of disposal at the landfill itself. For the incineration system, collection and transfer costs are similar to the landfill system, but account for about half of the total cost of the system. The remaining 50 per cent of costs (ca € 80 /tonne) are associated with the incineration process itself, of which about three-quarters (ca € 60 / tonne) is for plant & machinery and site development. Gas treatment costs (in terms of reagents and residues from acid gas abatement) for MSW incineration account for less than 5 per cent of the total cost of the incineration process.

already taking place in order to increase the recycling of concrete and brickwork to secondary aggregates. The segregation of PVC waste for landfilling could therefore be undertaken on demolition sites at the same time as this major segregation activity, so reducing costs associated specifically with PVC diversion. The cost elements of interest will be mostly those of providing additional containers for the segregated PVC waste. This is expected to be in the range € 10-50 /tonne of PVC waste segregated. We have adopted an intermediate value of € 30 /tonne for this analysis. Scenario 3 may require changes in regulations in some countries to allow the direct landfilling of PVC wastes.

5.1.3 Net recycling costs and quantities of PVC diverted

In Table 42, we compare the net costs of recycling with the avoided costs of incineration (with and without the 'incinerator subsidy') and landfill. Mid range values of the net recycling costs reported previously by Prognos (see Table 4) have been used where available – including for rigid building profiles, pipes and flooring. For other products, the very low rates of recycling mean that cost data are very scarce. The values proposed in the table for packaging wastes are based on mixed plastic waste recycling in Germany & Austria. Costs for recycling of household and commercial wastes are expected to be slightly higher, whilst costs for recycling electrical and electronic wastes may be similar to packaging waste because of reduced collection costs – the waste being available in higher concentrations from dismantlers' premises.

The costs of diversion from incineration or landfill to recycling (as in scenarios 1 and 2) or of diversion from incineration to landfill (for constructional wastes only in scenario 3) are shown in the five right-most columns of the table. Note that the results here are expressed on a € per tonne of waste basis. The results show that even when the avoided 'incineration subsidy' is taken into account, diversion of PVC waste from incineration to recycling results in a net increase in costs, except in the case of rigid construction products and cables, where net recycling costs are lowest. Diversion from landfill to recycling results in a net cost increase for all products, except cables. Diversion of constructional PVC products from incineration to landfill gives rise to a cost saving of € 35/tonne, excluding the 'incineration subsidy' and a saving of € 120 to 200 /tonne with it.

The total amounts of PVC waste from various products and applications being diverted from incineration or landfill to recycling under scenarios 1 and 2 (for both the high and low incineration futures) are shown in Table 43. Total quantities of waste diverted under all three scenarios have already been presented in Table 7. We do not need to take account of the individual applications and products diverted in scenario 3, since recycling is not involved. From the information on costs and quantities of waste diverted, we can estimate the total costs of each of the scenarios. This is presented in the following section.

Table 42: Costs of diverting PVC waste from incineration or landfill to recycling, and incineration to landfill. Units €/tonne.

PVC product / application (see Table 9 for product details)	Net cost of recycling	'Incinerator subsidy'	Incineration charges	Landfill charges	Segregation for landfilling	Incineration to recycling (scenarios 1 and 2)		Landfill to recycling (scenarios 1 and 2)	Incineration to landfill (scenario 3)	
						Excluding avoided 'incineration subsidy'	Including avoided 'incineration subsidy'		Excluding avoided 'incineration subsidy'	Including avoided 'incineration subsidy'
Column label / calculation	**A**	**B**	**C**	**D**	**E**	**A-C**	**A-(B+C)**	**A-D**	**(D+E)-C**	**(D+E)-(B+C)**
Rigid applications										
Rigid construction, HQR (pipes, windows, cable trays and other rigid profiles)	250	165	165	100	30	85	-80	150	-35	-200
Rigid packaging, LQR (films & bottles)	850				n/a	685	520	750	n/a	n/a
Rigid H&C, HQR	1000				n/a	835	670	900	n/a	n/a
Flexible applications										
Flexible construction, LQR, cables	0	85			30	-165	-250	-100	-35	-120
Flexible constructional, HQR, flooring	350					185	100	250	-35	-120
Flexible constructional, HQR, hoses & profiles	400					235	150	300	-35	-120
Flexible H&C, HQR	1000				n/a	835	750	900	n/a	n/a
Flexible E&E, LQR	850				n/a	685	600	750	n/a	n/a

Table 43: Quantities of PVC waste diverted from incineration or landfill to recycling during 2000-2020, EU-21, ktonnes.

Scenario:	**Scenario 1**				**Scenario 2**				**Scenario 1**		**Scenario 2**	
Diversion to recycling from:	**Incineration**		**Landfill**		**Incineration**		**Landfill**		**Total**			
Incineration future:	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
PVC application / product (see Table 9 for product details)	**Cumulative waste diverted to recycling, 2000-2020, ktonnes**											
Rigid construction, HQR (pipes, windows, cable trays and other rigid profiles)	1,611	1,405	2,337	2,543	1,977	1,724	2,874	3,127	3,948	3,948	4,851	4,851
Rigid packaging, LQR (films & bottles)	0	0	0	0	151	135	192	208	0	0	343	343
Rigid H&C, HQR	0	0	0	0	554	486	629	697	0	0	1,183	1,183
Flexible construction, LQR, cables	0	0	0	0	102	89	151	163	0	0	253	253
Flexible constructional, HQR, flooring	221	192	338	367	310	269	478	519	558	558	788	788
Flexible constructional, HQR, hoses & profiles	0	0	0	0	183	158	289	313	0	0	472	472
Flexible H&C, HQR	0	0	0	0	268	233	313	347	0	0	580	580
Flexible E&E, LQR	0	0	0	0	529	453	769	845	0	0	1,298	1,298
Total rigid	**1,611**	**1,405**	**2,337**	**2,543**	**2,681**	**2,345**	**3,696**	**4,032**	**3,948**	**3,948**	**6,377**	**6,377**
Total flexible	**221**	**192**	**338**	**367**	**1,392**	**1,203**	**1,998**	**2,188**	**558**	**558**	**3,390**	**3,390**
Total Rigid + Flexible	**1,832**	**1,597**	**2,675**	**2,910**	**4,073**	**3,548**	**5,694**	**6,220**	**4,507**	**4,507**	**9,768**	**9,768**

(a) HQR = high quality recycling, LQR = low quality recycling.

5.2 OVERALL WASTE MANAGEMENT COSTS OF THE SCENARIOS

The avoided costs (i.e. 'incinerator subsidy', incineration and landfill charges) of the scenarios are summarised in Table 44 and shown as present value costs discounted at 4%, on a total cost basis over the 20 year horizon and as annualised costs in million € year for the EU-21. Results for discount rates of 0, 2 and 6% are given in Appendix 7. Table 45 show the costs incurred (i.e. recycling, landfilling and sorting for landfill costs) as a result of the scenarios, and Table 46 and Table 47 present the overall net cost (i.e. avoided + incurred costs). The tables show the results as total costs over the 20 year time horizon, and annualised costs (shown by the shaded cells).

Table 44: Scenario analysis result - present value cumulative and annualised avoided costs for EU-21, 2000-2020 at 4% discount rate.

'Incinerator subsidy'	**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	*High*	*Low*	*High*	*Low*	*High*	*Low*
Rigid PVC	-161	-141	-268	-235	-441	-383
Flexible PVC	-11	-10	-72	-62	-343	-296
Total	**-173**	**-150**	**-340**	**-297**	**-784**	**-679**
Annualised costs, million € /year						
Rigid PVC	-11.9	-10.3	-19.7	-17.3	-32.4	-28.2
Flexible PVC	-0.8	-0.7	-5.3	-4.6	-25.2	-21.8
Total	**-12.7**	**-11.1**	**-25.0**	**-21.8**	**-57.7**	**-49.9**

Incineration charges	**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	*High*	*Low*	*High*	*Low*	*High*	*Low*
Rigid PVC	-161	-141	-268	-235	-441	-383
Flexible PVC	-22	-19	-139	-120	-666	-575
Total	**-183**	**-160**	**-407**	**-355**	**-1107**	**-957**
Annualised costs, million € /year						
Rigid PVC	-11.9	-10.3	-19.7	-17.3	-32.4	-28.2
Flexible PVC	-1.6	-1.4	-10.2	-8.9	-49.0	-42.3
Total	**-13.5**	**-11.8**	**-30.0**	**-26.1**	**-81.4**	**-70.5**

Landfill charges	**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	*High*	*Low*	*High*	*Low*	*High*	*Low*
Rigid PVC	-142	-154	-224	-244		
Flexible PVC	-20	-22	-121	-133		
Total	**-162**	**-176**	**-345**	**-377**		
Annualised costs, million € /year						
Rigid PVC	-10.4	-11.3	-16.5	-18.0		
Flexible PVC	-1.5	-1.6	-8.9	-9.8		
Total	**-11.9**	**-13.0**	**-25.4**	**-27.7**		

Table 45: Scenario analysis result - present value cumulative and annualised incurred costs for EU-21, 2000-2020 at 4% discount rate.

Sorting for landfilling	**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	*High*	*Low*	*High*	*Low*	*High*	*Low*
Rigid PVC					80	70
Flexible PVC					121	104
Total					**201**	**174**
Annualised costs, million € /year						
Rigid PVC					5.9	5.1
Flexible PVC					8.9	7.7
Total					**14.8**	**12.8**

Landfill charges	**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	*High*	*Low*	*High*	*Low*	*High*	*Low*
Rigid PVC					267	232
Flexible PVC					404	348
Total					**671**	**580**
Annualised costs, million € /year						
Rigid PVC					19.7	17.1
Flexible PVC					29.7	25.6
Total					**49.4**	**42.7**

Recycling	**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	*High*	*Low*	*High*	*Low*	*High*	*Low*
Rigid construction, HCR	598	598	735	735		
Rigid packaging, HCR	0	0	177	177		
Rigid H&C, LQR	0	0	717	717		
Flexible cables LQR	0	0	0	0		
Flexible flooring, HQR	119	119	167	167		
Flexible hoses & profiles, HQR	0	0	114	114		
Flexible H&C, HQR	0	0	352	352		
Flexible E&E, LQR	0	0	669	669		
Rigid PVC	**598**	**598**	**1629**	**1629**		
Flexible PVC	**119**	**119**	**1302**	**1302**		
Total	**717**	**717**	**2932**	**2932**		
Annualised costs, million € /year						
Rigid construction, HCR	44.0	44.0	54.1	54.1		
Rigid packaging, HCR	0.0	0.0	13.0	13.0		
Rigid H&C, LQR	0.0	0.0	52.8	52.8		
Flexible cables LQR	0.0	0.0	0.0	0.0		
Flexible flooring, HQR	8.7	8.7	12.3	12.3		
Flexible hoses & profiles, HQR	0.0	0.0	8.4	8.4		
Flexible H&C, HQR	0.0	0.0	25.9	25.9		
Flexible E&E, LQR	0.0	0.0	49.2	49.2		
Rigid PVC	**44.0**	**44.0**	**119.9**	**119.9**		
Flexible PVC	**8.7**	**8.7**	**95.8**	**95.8**		
Total	**52.8**	**52.8**	**215.7**	**215.7**		

Table 46: Scenario analysis result - present value cumulative net scenario costs for EU-21, 2000-2020 at 4% discount rate.

	Scenario 1		**Scenario 2**		**Scenario 3**	
Total costs, million €	*High*	*Low*	*High*	*Low*	*High*	*Low*
Excluding incinerator subsidy						
Rigid	296	304	1137	1150	-94	-81
Flexible	76	77	1042	1049	-141	-122
Total	372	381	2179	2200	-235	-203
Including incinerator subsidy						
Rigid	134	163	869	916	-534	-464
Flexible	65	67	970	987	-484	-418
Total	199	230	1839	1903	-1019	-882

Table 47: Scenario analysis result - present value annualised net scenario costs for EU-21, 2000-2020 at 4% discount rate.

	Scenario 1		**Scenario 2**		**Scenario 3**	
Annualised costs, million € /year	*High*	*Low*	*High*	*Low*	*High*	*Low*
Excluding incinerator subsidy						
Rigid	22	22	84	85	-7	-6
Flexible	6	6	77	77	-10	-9
Total	27	28	160	162	-17	-15
Including incinerator subsidy						
Rigid	10	12	64	67	-39	-34
Flexible	5	5	71	73	-36	-31
Total	15	17	135	140	-75	-65

Table 48: Scenario analysis, present value costs per tonne of waste diverted at 4% discount rate.

	Scenario 1		**Scenario 2**		**Scenario 3**	
Cost € / tonne	*High*	*Low*	*High*	*Low*	*High*	*Low*
Excluding ‘incinerator subsidy’	82	84	223	225	-21	-21
Including ‘incinerator subsidy’	44	51	188	194	-92	-92

The results in Table 46 indicate that the additional costs of diverting PVC from landfill and incineration to recycling will be about € 370-380 million for scenario 1 and about € 2200 million for scenario 2, excluding the additional costs of the ‘incinerator subsidy’. When the latter is taken into account, the costs fall to about € 200-230 million (scenario 1) to € 1900 million (scenario 2). Scenario 3 achieves a net cost saving without the subsidy of over € 200 million, or over € 880 million with the avoided ‘subsidy’. Diversion from incineration to landfill may, however, require changes to national legislation in some countries. It is important to bear in mind that scenario 3 is based on the assumption that only construction PVC waste is diverted from incineration to landfill. The additional costs for the segregation of PVC in this waste stream are expected to be relatively low since an increasing amount of sorting is already being undertaken to recover secondary aggregates. The costs of segregation of other waste streams where PVC is a smaller and less distinct component, such as in household and commercial waste, is expected to be considerably higher. In the case of scenario 3, net cost savings result from diversion from incineration to landfill (excluding the ‘incinerator subsidy’) when the additional present value costs of sorting for diversion to landfill are less than ~€ 40/tonne. The average cost of € 30/tonne used in this study equates to a present value of € 20/tonne for the additional sorting step.

The corresponding annualised net costs for the scenarios are given in Table 47 and the present value costs per tonne diverted are shown in Table 48.

The sensitivity of the results to variations in the base costs has been explored and the results are illustrated for the average PVC waste under the high incineration future (including the ‘incinerator subsidy’) in the following spider diagrams. The spider diagrams show the effect on the overall cost of the scenarios when each of the cost elements is varied in turn by a factor of 0.5 or 1.5 times its base value, which is taken to be 1. The steeper the gradient of the line for each cost element, the greater is its impact on the overall cost.

For the first two scenarios (Figure 13 and Figure 14), the dominant impact on net costs comes from changes in net recycling cost, with variations in the remaining cost elements having almost equal impact. Note that the lines intersect at the base value of 1 at € 199 million for scenario 1 and € 1839 million for scenario 2, as expected from the results shown in Table 46. The impact of variations in recycling costs on the overall costs of the scenarios increases markedly between scenarios 1 and 2, as the average net recycling cost increases from € 160/tonne in scenario 1 to over € 300/tonne (present value at 4% discount rate). This is particularly important for scenario 2, where estimates of net recycling costs for some waste streams are particularly uncertain – for example, non-constructional applications.

Net costs of recycling are closely linked to the price of virgin PVC. As virgin PVC prices rise, so to does the price of recyclate, allowing the net cost to fall. The net costs of scenarios 1 and 2 over the next 20 years will therefore depend on the price of virgin resin, which is in turn linked to the costs of hydrocarbon feedstocks and energy. In the case of scenario 3, which involves no increase in recycling, the net cost depends closely on the relative costs of incineration and landfilling.

Figure 13: Effect of varying base costs by + or minus 50% on the net cost of scenario 1 (high incineration, average PVC waste composition), present value net costs at 4% discount rate, million € .

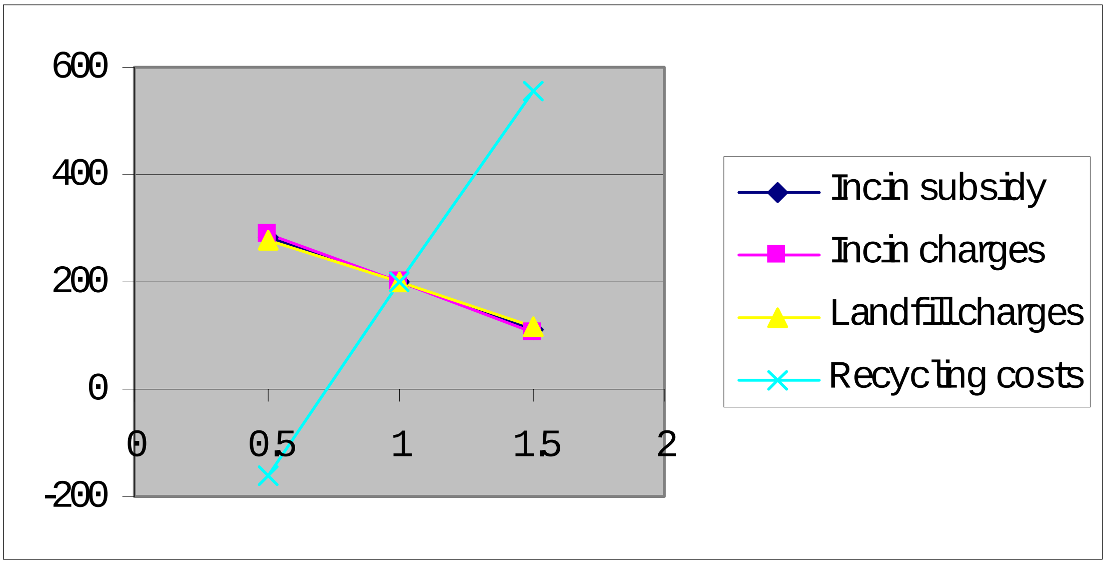


Figure 14: Effect of varying base costs by + or minus 50% on the net cost of scenario 2 (high incineration, average PVC waste composition), present value net costs at 4% discount rate, million € .

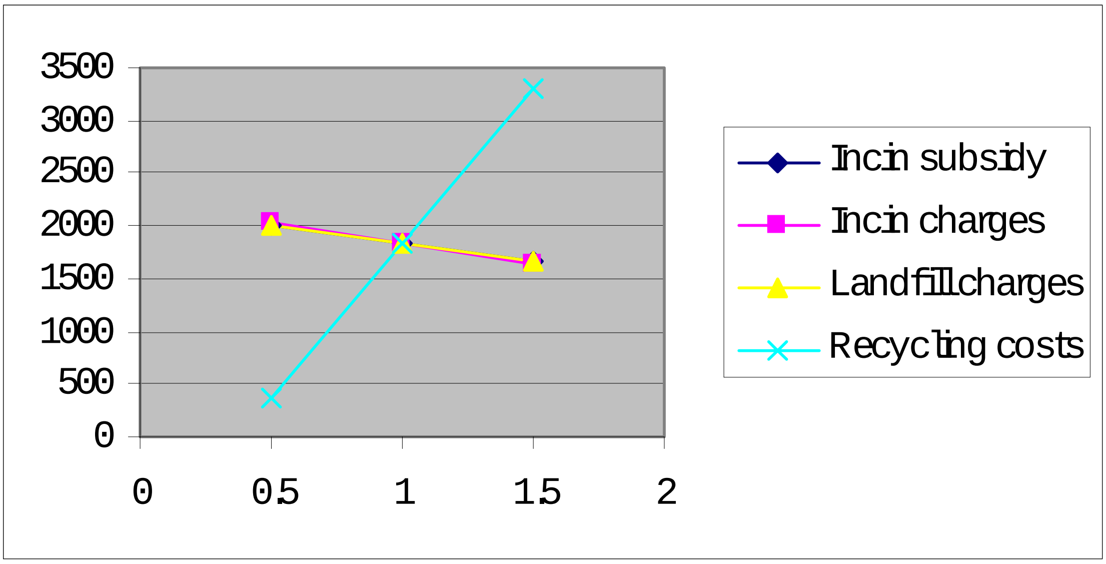
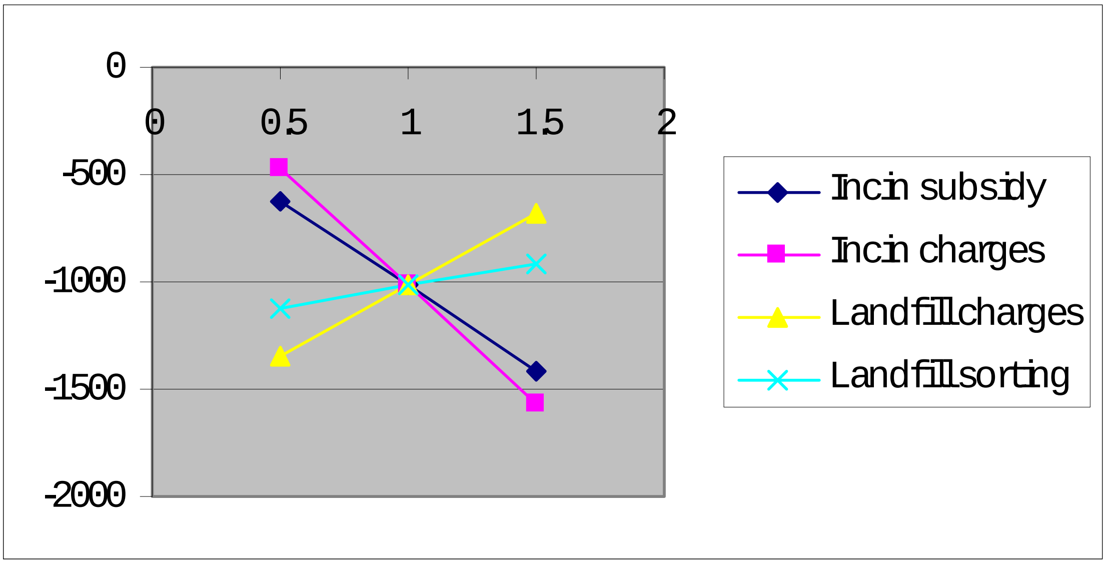


Figure 15: Effect of varying base costs by + or minus 50% on the net cost of scenario 3 (high incineration, average PVC waste composition), present value net costs at 4% discount rate, million € .



The results presented here support the following conclusions:

- Under scenario 1, some 4.5 million tonnes of PVC in building profiles and flooring would be diverted to recycling over the next 20 years. This would require support at the level of about € 370-380 million over this period (annualised cost about € 28 million) (at 4% discount rate).

- Diversion from incineration would avoid the additional cost already paid for PVC incineration as a result of the higher costs of emission control for this component of the waste that is not internalised within the waste disposal charge. Taking this avoided cost into account reduces the total cost of scenario 1 to between €200 million (low incineration future) to 230 million (high incineration future), equivalent to an annual cost of € 15 million to 17 million.

- Under scenario 2, some 9.8 million tonnes of PVC is assumed to be diverted from incineration and landfill to recycling. The additional total cost needed in support measures for recycling is estimated to be about € 2200 million, excluding the avoided incineration subsidy. The net cost would be about € 1900 million when the avoided cost of the 'incineration subsidy' is taken into account. The corresponding annualised costs for scenario 2 are about € 160 million (without 'incineration subsidy') and about € 140 million, net of the avoided 'incineration subsidy'.

- Scenario 3, which envisages the diversion of some 9.6 to 11 million tonnes of PVC from incineration to landfill could produce a net *saving* of € 200-235 million, or up to € 1000 million if the avoided 'incineration subsidy' is taken into account. Corresponding annualised cost savings from scenario 3 amount to

€ 16 million/year (excluding avoided 'incineration subsidy') to about € 70 million (taking account of the avoided subsidy).

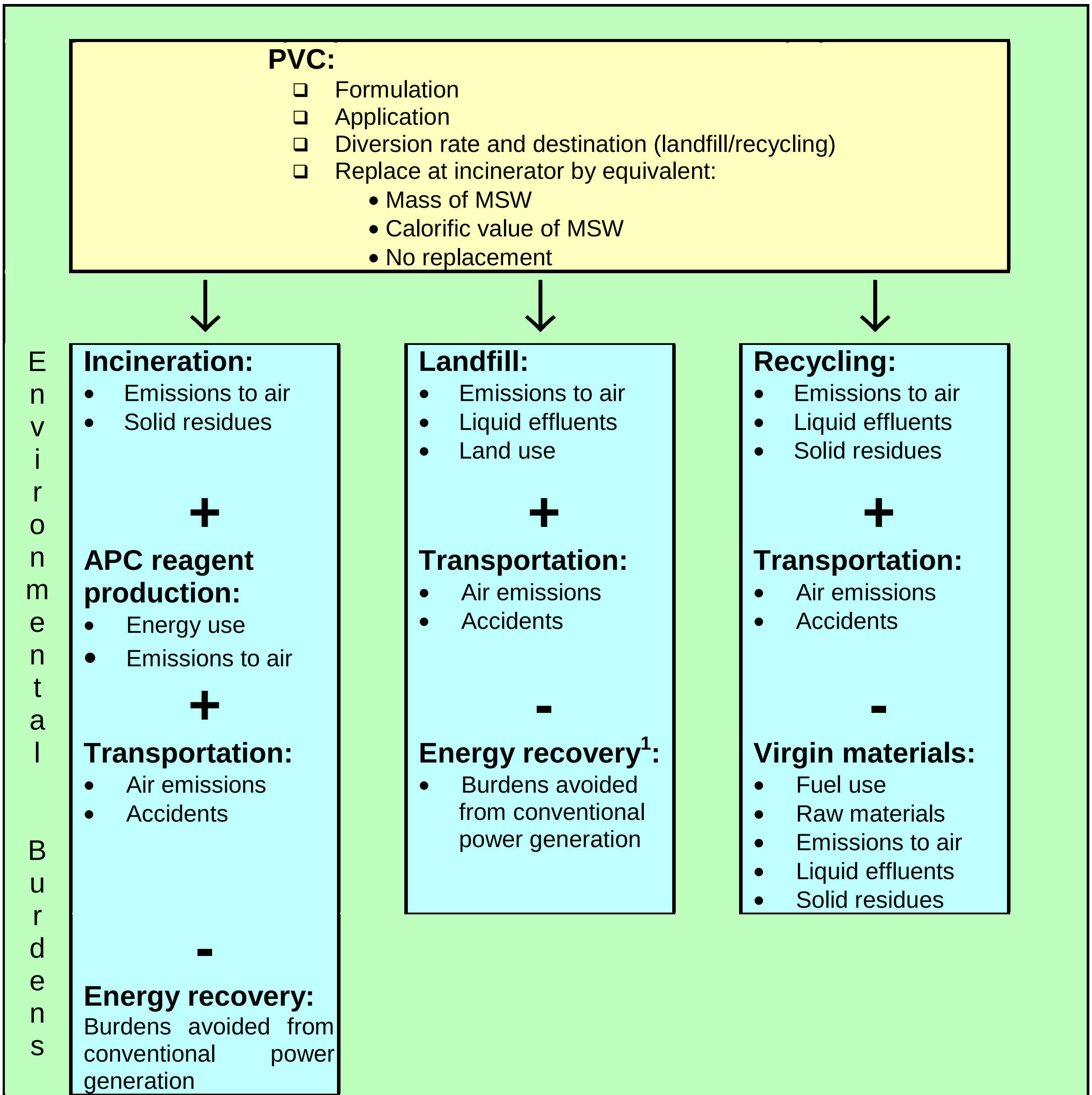
- The dominant factor in the net cost of scenario 1 and 2 is the cost of recycling, which in turn varies markedly (and inversely) with virgin resin prices. Scenario 3 would require changes in member state legislation to allow PVC waste to be diverted from incineration to landfill.

Having evaluated the waste management costs of the scenarios, we will now report the evaluation of the *environmental* costs of the scenarios, in the next section.

6 Environmental analysis

Previous sections have described the derivation of inventories of the burdens arising from the various Scenarios considered. This forms the starting point for the assessment of the environmental impacts and associated economic benefits. An overview of the analysis so far is provided in Figure 16, and a list of the quantified burdens is given in Table 49.

Figure 16: Linking the diversion of PVC from incineration to environmental burdens.



Note 1) Energy recovery from landfill here relates to the effect of diversion of PVC from incineration on the amount of municipal solid waste sent to landfill. This has not been quantified here. Given the quantities of material involved this is not a significant omission.

Table 49: Burdens quantified during the study

Stage	Burdens
Incineration	Air emissions: PM_{10}, HCl, NO_x, SO_2, Cd, Pb, dioxin, CO_2 Solid wastes from; APC: $CaCl_2$, $CaSO_4$, $Ca(OH)_2$, Cd, Pb Fly ash & grate ash: Residue, chloride, sulphate, Cd, Pb
Energy recovery[1]	Mainly NOx, CO_2
APC reagent production	Air emissions: PM_{10}, NO_x, SO_2, CO_2 Electricity used and associated emissions: CO_2, NO_x, SO_2, PM_{10}
Transportation	Air emissions: PM_{10}, NO_x, SO_2, CO_2 Accidents
Landfill	CH_4, CO_2 ,contamination of the landfill[2] with Cd, Pb, plasticisers
Transportation	Air emissions: PM_{10}, NO_x, SO_2, CO_2 Accidents
Recycling	Burdens from transportation and electricity use
Transportation	Air emissions: PM_{10}, NO_x, SO_2, CO_2 Accidents
Production of virgin materials	Fuel: coal, oil, gas, hydro, nuclear, other Feedstock: oil, gas Other raw materials: iron ore, limestone, water, bauxite, sodium chloride, sand Air emissions: dust, CO, CO_2, SO_2, NO_x, Cl_2, HCl, hydrocarbons, metals, chlorinated organics Liquid effluents: BOD, COD, acidity, metals, chloride, dissolved organic compounds, suspended solids, oil, dissolved solids, other nitrogen, chlorinated organics, sulphate, sodium Solid wastes: industrial wastes, mineral waste, slag and ash, inert chemicals, regulated chemicals

Notes:

1. In this study electricity from incineration is assumed to offset an equivalent amount of electricity generated by a Combined Cycle Gas Turbine power station. This is assumed to be the dominant form of marginal plant across Europe in the time period covered by this study. The main emissions avoided are thus NO_x and CO_2.
2. The term 'contamination of the landfill' is used to indicate that the problem of contamination is not restricted to leachate. The presence of significant quantities of heavy metals and plasticisers in landfill may affect future use of sites, whether or not the contamination has reached the liquid phase.

Comparison of the results given above showing the quantities of emissions and other burdens from the scenarios relevant to this study demonstrates that no single diversion route performs consistently best or worst from an environmental perspective (see Table 37 in Section 4.7). This is not surprising, given the complexity of the effects of diverting PVC from incineration.

The use of impact quantification and monetisation seeks to assist interpretation of these burdens. This is done by first quantifying the environmental harm linked to each burden in terms of health effects (e.g. deaths or hospital admissions linked to air pollution), damage to buildings, changes in crop yield, etc. Once this is done each type of impact is monetised to provide a common scale for comparison of effects, both between the different types of impact and against costs. There are well-known problems with this type of analysis: it is not possible to quantify every type of effect and results are prone to a significant level of uncertainty. The view taken here is that the correct approach for dealing with these problems is to quantify to the extent possible, review omissions, and to investigate the sensitivity of the outcome of the analysis to potential ranges in the quantified benefits. This essentially pragmatic approach was also followed in a number of other recent studies carried out by the study team for the European Commission[29].

6.1 METHODS FOR QUANTIFYING BENEFITS

The analysis adopted here is largely based on extrapolation of results derived using the ExternE Project methodology[30]. This follows a logical progression from emission to assessment of exposures, impacts and associated economic damages, as shown in Figure 17.

Figure 17. Pathway for quantification of benefits and monetisation.

Pollution load	→ Concentration, deposition
↓	
Stock at risk	→ Distribution of people, etc.
↓	
Sensitivity of stock at risk	→ Baseline mortality, etc.
↓	
Exposure-response functions	→ Rate of damage/unit pollutant
↓	
Impact assessment	→ Change in crop yield, mortality, etc
↓	
Valuation	→ Willingness to pay/accept, etc.

This methodology has been applied consistently (using the same dispersion models, data on stock at risk, etc.) across the EU by the team working on the National Implementation of the ExternE Project[31]. This study provides country specific estimates of damages per tonne of pollutant emitted for three of the most important pollutants likely to influence the results of the study – SO_2, NO_x and PM_{10} for all countries of the EU-15 except Luxembourg. Methods used in the calculation of these data are described in the ExternE Methodology report[30] and summarised briefly in Appendix 8. Here we multiply estimates of damage (taken from the ExternE study, and analyses on the incineration, national emission ceilings and ozone Directives) per tonne of pollutant emitted by emissions from each scenario, rather than tracing through all of the stages shown in Figure 17.

The need for country-specific estimates of damage arises because of the extent of variation in damage. Emissions from countries in the centre of Europe will cause more damage to health (which tends to dominate economic assessments of air pollution) than those from countries around the fringe of Europe, because more people will be exposed. As illustration, the results given by Saez and Linares point to a factor 10 difference between damages per tonne in Finland and those in France (Table 50). There is also of course variation in damage according to location within a country. This has not been explicitly accounted for here, because the data on waste arisings are only available at the national level.

There are some differences between the ExternE analysis for SO_2, NO_x and PM_{10} compared to the work carried out on the National Emission Ceilings Directive and the Ozone Directive (and also the UNECE's Gothenburg Protocol)[32]. To start, the analysis presented here includes effects on health, materials and crops, but not to ecosystems, forests or through changes in visibility for the following reasons.

- Ecosystem effects can only be quantified to the extent of describing critical loads exceedence, and this cannot currently be monetised. Hence even if we were to quantify these changes the effect would still remain outside the formal CBA.

- Results from the work on forests for the NEC and ozone Directives showed that the *quantified* effects on forests were both very small and extremely uncertain.

- Quantified benefits from changes in visibility appeared highly significant. However, discussion of visibility effects concluded that they were likely to be overstated, reflecting views from the USA (all data on the costs of visibility reduction are of US origin) rather than from Europe. There appears almost no interest in this issue in Europe. The results on visibility were ranked as being the least certain of those quantified in the work on the ozone Directive.

A further difference relates to the use of a VOSL (value of statistical life) of €3.2 million, rather than the €2.2 million adopted in the NEC/ozone study. Much of this difference arises from the need to convert currency over different years (all calculations for the NEC/ozone work were expressed in 1990 currency). Slight differences arise also from review of the research data on the VOSL. [Note that from the results presented below this has almost no real effect on the outcome of the analysis].

Damages per tonne of pollutant for cadmium and dioxins emitted to the atmosphere were taken from an earlier report on the Incineration Directive[25]. Additional data for lead were taken from EFTEC (1996)[33]. Data were adjusted for all three pollutants to give country specific estimates, based on variation in PM_{10} damage per unit emitted in each country. The logic followed here is that a significant fraction of these three pollutants are emitted adsorbed onto particles. Effects are also linked to the pollutant in the form emitted – this is not the case for (e.g.) NO_x for which impacts tend to be linked in the main to secondary pollutants (NO_2, nitrate aerosols and ozone).

External cost data for the emissions identified so far are summarised by country in Table 50. These data were subsequently adapted by weighting damages in each country by MSW arisings (Table 51).

Table 50. External costs for SO_2, NO_x, PM_{10}, cadmium, lead and dioxins (€/tonne of pollutant).

Country	SO_2	NO_x	PM_{10}	Cd	Pb	Dioxin
Austria	9000	12900	16800	122000	10400	5.25E+08
Belgium & Luxembourg	11800	11800	24500	177000	15000	7.67E+08
Denmark	3600	3920	5030	36400	3100	1.57E+08
Finland	1370	1180	1840	13300	1100	5.74E+07
France	10600	14500	24900	180000	15400	7.78E+08
Germany	12100	13100	21600	156000	13000	6.75E+08
Greece	4360	4300	4940	35800	3000	1.55E+08
Ireland	4050	2880	4110	29700	2500	1.28E+08
Italy	8690	8510	10400	75200	6400	3.25E+08
Netherlands	6800	5760	15900	115000	9800	4.96E+08
Portugal	5220	6330	6440	46600	4000	2.01E+08
Spain	6680	7570	7650	55400	4700	2.39E+08
Sweden	2580	2150	3290	23800	2000	1.03E+08
UK	7620	7640	15000	108000	9240	4.69E+08

Data for the greenhouse gases were taken from the Global Warming Report[30] of the ExternE Project. It was recognised that the results for global warming damages are highly dependent on issues such as economic development and population growth (extending to 2100), as well as climate sensitivity. Also, on assumptions on the extent to which society will be able to adapt to meet the challenges of rising sea levels, etc. Ranges were therefore taken. These were necessarily very broad, ranging from €3.8 to 139 /tonne of CO_2.

The externalities data discussed so far are subject to a number of uncertainties, which are dealt with here by defining lower and upper bounds for damages from each pollutant as well as best estimates (Table 51). The rationale for developing these ranges is described below.

Table 51 Best estimates, and lower and upper bounds for the external costs associated with each pollutant, weighted (where appropriate) by national MSW arisings.

Externalities	Units	Best estimate	Low	High
SO_2	€/tonne pollutant	9,200	1,300	27,000
NO_x	€/tonne pollutant	10,000	1,100	30,000
PM_{10}	€/tonne pollutant	17,000	1,900	50,000
Cd	€/tonne pollutant	67,000	6,700	120,000
Pb	€/tonne pollutant	10,000	5,000	15,000
CH_4	€/tonne pollutant	210	43	1,600
CO_2	€/tonne pollutant	19	3.8	139
Dioxin	€/tonne pollutant	290,000,000	29,000,000	520,000,000
Electricity	€/MWh	17	2	49

The ranges shown in Table 51 were calculated as follows:
SO_2, NO_x, PM_{10}:

- Best estimate is based on inclusion of chronic effects on mortality, with mortality valued using the VOLY approach.
- Lower bound is estimated by including only acute effects on mortality, valuing them again using the VOLY approach.
- The upper bound is calculated using chronic effects on mortality and the VOSL approach.

Note that acute and chronic effects on mortality are not added together as this would lead to double counting: the functions dealing with chronic effects also account implicitly for acute effects.

Electricity:

- Best estimate is based on ExternE data for natural gas power stations (assumed here to be the marginal generating technology over the period of interest). Upper and lower bounds were quantified using the same logic as was used for SO_2, PM_{10} and NO_x and greenhouse gases.

Cadmium (Cd), dioxins:

- Upper bound is based on the earlier report on the Incineration Directive[19].
- Best estimate is based on the assumption that 50% of those contracting cancer through pollutant exposure die, and 50% recover after treatment.
- The lower estimate is a factor 10 lower than the best estimate, stripping out safety factors introduced in the development of risk factors.

Lead (Pb)

- A nominal range of ±50% has been used for the range for lead. Damages from lead are so small that this has almost no effect on the analysis.

Greenhouse gases

- Data for the greenhouse gases were taken from the Global Warming Report[30] of the ExternE Project. It was recognised that the results for global warming damages are highly dependent on issues such as economic development and population growth (extending to 2100), as well as climate sensitivity. Also, on assumptions on the extent to which society will be able to adapt to meet the challenges of rising sea levels, etc. Ranges were therefore taken. These were necessarily very broad, for CO_2 for example ranging from € 3.8 to 139 /tonne of CO_2. This is a similar range to that discussed by the IPCC. The best estimate is taken towards the lower end of this range, of roughly the same magnitude as results from many other global warming assessments. These ranges for climate change analysis are illustrative, in that the analysis that generated them was unable to investigate some aspects of the climate change problem, such as effects on the frequency of severe weather events. Results could certainly be generated outside of this range using plausible assumptions, though the ranges given here cover most available estimates.

Consideration of results from the ExternE Project and the work on the NEC/ozone Directives suggests that this list covers the main uncertainties likely to affect the benefits analysis in this study. These ranges could be further debated, but in many cases this would have no effect on the outcome of the analysis.

Whilst Table 51 provides data for each pollutant, it does not demonstrate the split in damages between different effects (e.g. on mortality, morbidity and other receptors). Such a split will vary according to the assumptions on which results are based. So, for example, the contribution of mortality impacts to total externalities will vary from perhaps only 10% at the bottom of the range for PM_{10}, where chronic effects on mortality are excluded and the VOLY approach is used for valuation of the acute effects of air pollution exposure, to as much as 90% at the upper end of the range. However, it can reasonably be concluded that quantified non-health effects are not of great importance to this analysis, contributing no more than about 10% of the total externality for any pollutant.

Inevitably there are a number of effects omitted from the quantified assessment of impacts and benefits because of a lack of data. Where such omissions appear potentially important a qualitative assessment is reported. This is the case for cadmium, lead and phthalate plasticisers sent to landfill.

Impacts quantified in the study are listed in Table 52. Table 53 shows the burdens for which a monetary evaluation was not carried out, and the reasons for discontinuing the analysis, where appropriate. This second list appears extensive, and at first glance may suggest that there is a strong bias to underestimation of externalities. However, many of the burdens listed look unlikely to cause significant harm, either because of the nature of the burden, or the likely effectiveness of regulation in controlling impacts.

Table 52: Impacts quantified in the study.

Effect	Comments
Health	
SO_2, PM_{10}, NO_3 and SO_4 aerosols	
acute – mortality	
chronic - mortality	Limited availability of data, Excludes SO_2 direct
acute - morbidity	
chronic - morbidity	Excludes SO_2 direct effect (but not SO_4)
Materials	
Acid effects on utilitarian buildings	Effects on buildings and other objects of cultural significance are excluded from analysis through a lack of data
Crops	
Direct effects of SO_2 and O_3 on crop yield	Most important of the effects of air pollution on agriculture
Indirect SO_2 and O_3 effects on livestock	These effects are of secondary importance to the direct effects of SO_2 and O_3 on crops
N deposition as fertiliser	Likely to be negligible
Acidification/liming	Effect of atmospheric deposition likely to be negligible
Accidents	Death and injury from road traffic accidents linked to movement of materials, waste, etc.
Impacts from changes in demand for electricity generation	Includes a wide range of impacts. Assumed that gas-fired CCGT are the type of power plant at the margin in the period 2000 to 2010.
Climate change effects from changes in emissions of CO_2 and CH_4	Diverse impacts ranging from effects on agriculture to energy use

Table 53: Quantified burdens for which impacts were not estimated in this study.

Burden/impact	Reason for not proceeding to quantification
Solid residues from incineration and landfilling: APC residues: calcium and sodium chloride excess APC reagent Fly ash and grate ash: salts heavy metals Raw PVC sent to landfill Heavy metals Plasticisers	Lack of data on impacts and values. Impacts should be minimised by sending waste materials to a properly regulated landfill.
Raw materials for PVC manufacture: iron ore limestone water bauxite sodium chloride sand	These materials are extracted from the natural environment. Burdens associated with extraction (blasting for limestone, dust emissions from quarries, etc.) are not included, but from previous analysis considered unlikely to be significant in the context of the overall analysis (see reference 30). Virtually all-subsequent burdens (through transport and processing) are included elsewhere in the inventory of burdens.
Liquid effluent from PVC manufacture: BOD COD acidity metals chloride dissolved organic compounds suspended solids oil dissolved solids other nitrogen chlorinated organics sulphate sodium	Lack of data. Effective regulation should avoid significant impacts to the extent that these are known. Accumulation of waste material in sediments may prove problematic in the long term.
Solid wastes from PVC manufacture: industrial wastes mineral waste slag and ash inert chemicals regulated chemicals	Lack of data on effects and valuation. Impacts should be minimised by disposing of waste materials through properly regulated routes.
Unquantified effects of air pollutants	
Effects of NO_2, Cl_2, HCl, chlorinated organics and VOCs on health	Lack of data on dose response, lack of speciated inventory for VOCs
Altruistic impacts following air pollution damage to health	No data for a reliable quantification
Effects of acidity on cultural heritage, effects of ozone on rubber	Lack of a European inventory of stock at risk, and lack of valuation data for cultural heritage
Effects of air pollutants on ecosystems, agriculture and forestry	Lack of data on change in ozone levels from changes in NO_x and VOC emissions. Lack of data on ecosystem response and valuation.
Effects of air pollution on visibility	Lack of European data.

6.2 RESULTS

The major sources of environmental costs to the system comes from PVC manufacture and incineration. In the former (Figure 18), the main source is NO_x, SO_2 , electricity and dust (taken to be all PM_{10}) whilst for incineration (Figure 19) the main impact is from CO_2 . The values plotted are the averages calculated when the PVC diverted from incineration is either not replaced by MSW, or replaced on a mass, or heat equivalent basis. Quantified landfill externalities[o] are less than € 5/tonne, almost entirely due to transport accidents, and recycling, for which the main externalities quantified are electricity use (€ 70/tonne) and transport accidents (under € 10/tonne).

Figure 18: Environmental costs of manufacturing rigid PVC avoided by high quality recycling, € /tonne, based on 'best estimates' of external costs.

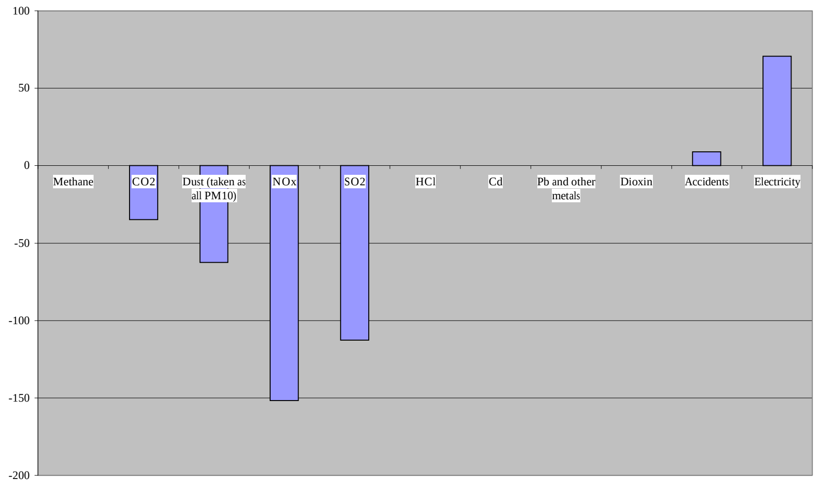
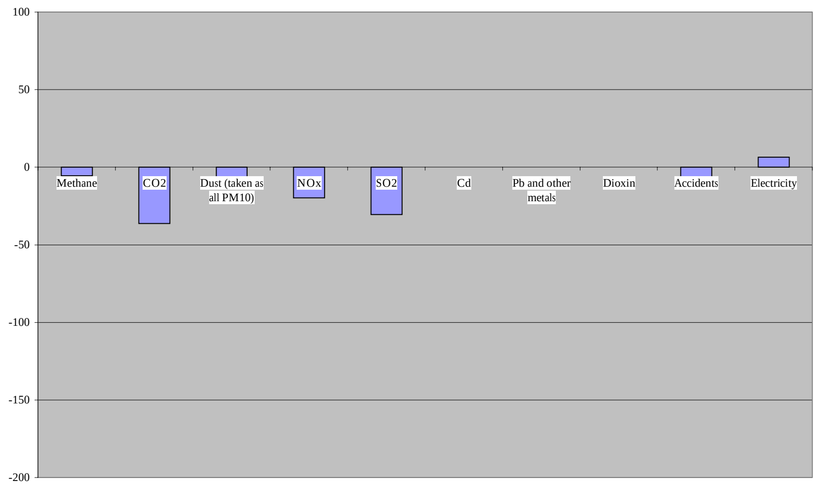


Figure 19: Environmental costs saved by avoiding incineration of rigid PVC, € /tonne, based on 'best estimates' of external costs.



A summary of total quantified environmental costs associated with each of the diversion routes is shown in Table 54. The table is split in two, the top half dealing with rigid

[o] This is because there are no monetarised data available on the environmental impacts of waste deposited in landfills.

PVC, and the lower half, flexible. In each half the top five lines show environmental externalities (in €/tonne of waste diverted) obtained when the value for the various externalities is set at the 'best estimates' shown in Table 51. Detailed results for each of the environmental burdens making up the total externalities are given in Appendix 9. The dominant externalities with respect to both total benefit and uncertainty are those associated with NO_x, SO_2, PM_{10} and CO_2. It can also be seen that the issue of PVC diverted from incineration being replaced by MSW has virtually no effect on the results. The consequences of uncertainty in the quantification of externalities for air emissions of dioxin, cadmium and lead are very small because of the relatively low quantities emitted. As a result, the potential over-estimation of cadmium and lead emissions from incinerators resulting from the treatment of these burdens as outlined in section 3.4.1 has no significant impact on the analysis.

Table 54: Summary of total quantified externalities for each diversion route (€ /tonne).

Diversion route	Externality value	Rigid PVC Replacement basis of MSW for PVC at incinerator		
		none	mass	heat
Incineration to high quality recycling	Best estimate	-394	-393	-393
Incineration to low quality recycling	Best estimate	-54	-53	-53
Landfill to high quality recycling	Best estimate	-288	-288	-288
Landfill to low quality recycling	Best estimate	52	52	52
Incineration to landfill	Best estimate	-106	-105	-104
Incineration to high quality recycling	Low	-55	-58	-60
Incineration to high quality recycling	High	-1500	-1498	-1496

Diversion route	Externality value	Flexible PVC Replacement basis of MSW for PVC at incinerator		
		none	mass	heat
Incineration to high quality recycling	Best estimate	**-227**	**-226**	**-226**
Incineration to low quality recycling	Best estimate	**-24**	**-23**	**-22**
Landfill to high quality recycling	Best estimate	**-155**	**-155**	**-155**
Landfill to low quality recycling	Best estimate	**48**	**48**	**48**
Incineration to landfill	Best estimate	**-72**	**-71**	**-70**
Incineration to high quality recycling	Low	**-31**	**-34**	**-37**
Incineration to high quality recycling	High	**-955**	**-953**	**-950**

The last two lines in each half of the table illustrate the effects of taking alternative low and high estimates for the environmental externalities on the 'incineration to high quality recycling' diversion route. The dominant uncertainties relate to three issues:

- Valuation of mortality
- Inclusion of chronic effects on mortality
- Treatment of climate change impacts

We will first consider the total externalities when the valuations are set at their 'best estimates'. Diversion from incineration to high quality recycling shows the greatest benefits, at around €390/tonne (rigid) or about €230/tonne (flexible). Benefits of just under €290/tonne (rigid) and €155/tonne (flexible) come from diversion from landfill to high quality recycling. In contrast, diversion to low quality recycling (which is not credited with avoided burdens from manufacturing virgin resin) saves ~ €53/tonne (rigid) and ~€23/tonne (flexible) in the case of incineration and incurs a small cost increase (~€50 /tonne) for landfill. Savings due to diversion from incineration to landfill (scenario 3) amount to about € 100/tonne (rigid) and ~ €70 /tonne (flexible). The magnitude of impacts associated with diversion routes involving high quality recycling demonstrates the dominant impacts of avoided emissions from virgin compound manufacture on the environmental costs. This also explains the negligible impact of the 'incineration future' on the results, which is illustrated in Appendix 9. Because of this, subsequent results are presented as the mean of the high and low incineration futures.

We now compare the results for the 'incineration to high quality recycling' diversion route at alternative valuations of the externalities. Under the low values (penultimate line in each half of Table 54), the total externalities per tonne fall to a saving of less than ~€60 /tonne for rigid PVC and less than € 37/tonne for flexible. Under the high valuations (last line in each half of the Table), savings rise to ~€1500/tonne (rigid) and ~ € 950 (flexible). Similar variation around an order of magnitude either side of the best estimate would be seen in the results for other diversion routes. The impact of uncertainty in externality valuation on the outcome of the analysis is clearly very large, though from the outcome of previous analyses, is not unexpected. This issue is dealt again, below.

One of the most important omissions from the analysis relates to the disposal of material containing phthalates, cadmium and lead. Whilst the analysis does not quantify effects of these pollutants (other than through their minor contribution, in the context of this analysis, to air pollution), it is possible to comment on the differences in likely effect between different options. Incineration is an effective method for destroying phthalates. However, it will remove the heavy metals from the PVC matrix, transferring them to ash in which they are likely to be more mobile. In contrast, the heavy metals will remain tightly bound within the PVC matrix for both recycling and landfill options. Phthalates may, however, leach slowly from landfilled material[2]. Their impact on health and the environment will be dependent on treatment of collected leachate, the efficiency of leachate collection and other factors. Overall it is not clear which option is to be preferred with respect to management of cadmium, lead and phthalates.

The total quantified environmental costs for each scenario are shown in Table 55, as the mean values from the high and low incineration futures. The results are presented for the central discount rate of 4%, for rigid and flexible PVC and overall costs for both types together. Overall, external costs for the scenarios are negative in all cases, and with respect to all ranges investigated for different parameters. This denotes net (environmental and human health) benefits for those effects for which quantification has been possible. The results show that overall environmental benefits valued at about €M 850 to 1,400 could accrue as a result of implementing scenarios 1 or 2 and that there will be a smaller benefit (up to €M ~530) from scenario 3, based on 'best estimate' environmental valuations. . The major contribution to these results comes from diversion to high quality recycling, because of emissions avoided from the manufacture of virgin PVC. For scenarios 1 and 2, based on diversion to recycling, the greatest benefits come from rigid PVC, but for scenario 3, the benefits are more evenly distributed between rigid and flexible. The table also shows annualised costs per tonne of PVC waste. Overall cost savings are greatest for scenario 1 at € 62/tonne, € 102/tonne for scenario 2 and € 39/tonne for scenario 3. Further information for other discount rates is given in Appendix 9.

Table 56 expresses the results in terms of present value environmental costs per tonne of waste diverted at 4 per cent discount rate. The greatest benefits are seen with scenario 1 (saving € 188/tonne overall), which has the greatest proportion of high quality recycling, followed by scenario 2 (€ 142/tonne). Scenario 3 shows the lowest benefits at € 51/tonne.

Table 55: Overall environmental costs of the scenarios, € 2000-2020 (present value at 4% discount rate).

RIGID PVC	Scenario 1	Scenario 2	Scenario 3
Total cost, million Euro			
Low	-104	-160	-59
Best estimate	-786	-1205	-262
High	-2879	-4436	-1192
Annualised costs, million Euro/year			
Low	-8	-12	-4
Best estimate	-58	-89	-19
High	-212	-326	-88
FLEXIBLE PVC	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-8	-24	-62
Best estimate	-61	-184	-266
High	-244	-836	-1377
Annualised costs, million Euro/year			
Low	-1	-2	-5
Best estimate	-5	-14	-20
High	-18	-61	-101
RIGID + FLEXIBLE	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-112	-184	-121
Best estimate	-847	-1389	-529
High	-3123	-5271	-2569
Annualised costs, million Euro/year			
Low	-8	-14	-9
Best estimate	-62	-102	-39
High	-230	-388	-189

Table 56: Average present value environmental cost per tonne (present value at 4% discount rate).

RIGID PVC	Scenario 1	Scenario 2	Scenario 3
Low	-26	-25	-14
Best estimate	-199	-189	-64
High	-729	-696	-290
FLEXIBLE PVC	**Scenario 1**	**Scenario 2**	**Scenario 3**
Low	-14	-7	-10
Best estimate	-110	-54	-43
High	-437	-246	-222
OVERALL	**Scenario 1**	**Scenario 2**	**Scenario 3**
Low	-25	-19	-12
Best estimate	-188	-142	-51
High	-693	-540	-249

7 Conclusions

1. Arisings of post-consumer PVC waste in the EU-21 are predicted to increase by over 50 per cent in the next twenty years, from about 3.6 million tonnes to 6.4 million tonnes in 2020. The greatest increase will come from products in constructional and household and commercial products. Because most of the products in these applications have lifetimes of over a decade, their arrival in the waste stream is effectively de-coupled from present day production rates.

2. Over 80 per cent of PVC waste is currently disposed of in landfills, only 3 per cent is recycled and the remainder is incinerated, almost entirely in municipal solid waste incinerators. The very low rate of recycling is largely due to the difference in cost to waste producers for disposing of PVC waste via recycling as opposed to the cheaper options of landfilling or incineration. Present day recycling of PVC is largely restricted to low quality mechanical recycling of PVC into a mixed plastic waste, the economics of which is driven by the co-recovery of more valuable materials, such as metals. For high quality recycling, in which the recyclate directly substitutes for virgin compound, the selling price of the recycled PVC has been too low for recyclers to offer a disposal fee that can compete with landfill or incineration.

3. Policy initiatives at both the EU and Member State level are reducing the availability of landfill as a disposal option for raw wastes. As a result, we expect to see an increase in the use of incineration (with energy recovery) for disposing of those wastes that cannot be recycled. Incineration of PVC waste is expected to increase to about 41-46 per cent of arisings by 2020. A further 45-50 per cent will continue to go to landfill, with the remaining 9 per cent going to mechanical recycling, under baseline assumptions.

4. The study has evaluated the environmental burdens associated with alternative waste management options for PVC waste and where possible quantified these in monetary terms. The results have been used to evaluate alternative waste management scenarios involving increased mechanical recycling or the selective diversion of PVC waste from incineration to landfill.

5. Incineration is usually justified as a means of reducing the bulk of waste requiring ultimate disposal and to reduce its harmfulness, at the same time providing an opportune means of recovering energy. For each tonne of MSW incinerated, about 300 kg of bottom ash residue that can be recycled is produced, along with a further ~24 kg of fly ash and about 8 kg of residues from air pollution control (for average mix of APC plant) from the abatement of acid gas emissions. Fly ash and APC residues require disposal as hazardous waste, and sometimes require some form of stabilisation before disposal. In addition, for the average mix of APC plant used in the study, a 4-10 kg of neutralising reagent is required per tonne of MSW.

6. In contrast, incineration of PVC (with MSW) produces between about 560 kg of APC residue per tonne of flexible PVC, and about 900 kg per tonne of rigid PVC. The quantities of APC residue vary markedly with the technology employed. When PVC is incinerated, heavy metal stabilisers, such as lead and cadmium, are recovered as inorganic salts in fly ash and grate ash. Heavy metals in these residues are potentially more mobile in the landfill environment than when PVC is directly landfilled. However, organic additives of PVC, such as phthalic acid-based plasticisers, are effectively destroyed during incineration. Emissions to the atmosphere of NO_x, HCl, metals, dust, and dioxins (which are regulated to statutory emission limit values) are similar for MSW and PVC. Incinerator emissions of fossil CO_2 are, however, about five or six times higher for PVC than MSW. When account is taken of CO_2 emitted during the manufacture of alkali needed to abate acid gas emissions, the total CO_2 emitted from incinerating PVC increases to almost 8 times that for MSW. Up to twice as much energy can be recovered from PVC incineration as from the same mass of MSW. On the other hand, PVC resin is essentially inert under landfill conditions and metal stabilisers are effectively immobilised within the polymer matrix. Organic additives such as phthalic acid esters, however, may slowly leach out over time into the landfill leachate.

7. The principal direct environmental burdens from PVC recycling are energy use. In the case of high quality recycling, the additional environmental benefits accrue from the avoidance of burdens associated with PVC manufacture. Low quality recycling is not credited with these avoided burdens because mixed plastic waste cannot substitute for virgin PVC compound.

8. The analysis has considered mainly the environmental burdens and financial costs of diverting PVC waste from landfill and incineration to recycling. Scenario 1 is based on the assumption that recycling of rigid building profiles, windows and pipes, and flexible flooring, achieve their full recycling potential by 2010. Scenario 2 is based on the assumption that all PVC waste achieves its maximum recycling potential by 2010. A third scenario is based on the assumption that concern over PVC incineration is sufficient to force the removal of PVC from constructional applications from incineration and its diversion to landfill. This waste stream was chosen because PVC in building materials forms a significant and easily recognisable component of non-masonry construction waste. Segregation of non-masonry materials is necessary if construction wastes are to be recycled as secondary aggregates, in line with current trends.

9. The financial costs of diverting PVC waste from landfill or incineration to recycling is given by the net cost of recycling *less* the avoided costs of landfilling or incineration. The latest estimates of net recycling costs (including sorting, transportation and processing) indicate that the lowest costs are incurred for the recycling of building profiles windows and pipes made from rigid PVC, with a net recycling cost of € 200-300/tonne, followed by flooring made from flexible PVC, at € 300-400/tonne. Net costs for recycling PVC packaging waste, household and commercial applications and electrical and electronic wastes are estimated at over € 700/tonne. These costs compare with landfill disposal costs averaging € 100/tonne, including collection and transportation. Diversion of PVC waste from landfill to recycling will therefore incur additional costs of € 100 to over € 600/tonne of waste diverted, depending on the type of waste. One exception to the generally

unfavourable economics of PVC recycling is cables, but in this case the economics is driven by the value of the metal conductor (copper/aluminium) recovered as the main purpose of reprocessing.

10. Average costs for incineration (including collection, transportation, incineration and disposal of residue) are estimated to be € 165/tonne. Therefore diversion of PVC waste (excluding cables) from incineration to recycling will cost between € 35 and over € 535/tonne more, in terms of disposal costs paid by the waste producer. However, an additional factor needs to be considered. Incineration of PVC with MSW incurs additional operating costs for the incinerator in terms of reagents to abate acid gas emissions and for the treatment and disposal of residues, although these are partly offset by increased energy sales due to the higher calorific value of PVC compared with MSW. Overall, the additional costs of incinerating PVC in MSW amount to about € 85/tonne for flexible PVC and € 165/tonne for rigid formulations, assuming the estimated average mix of APC plant. This additional cost is paid indirectly by all users of the incinerator, and in effect amounts to a hidden subsidy for PVC incineration.

11. When the additional cost of PVC incineration and the incinerator disposal charge are both taken into account, diversion of some rigid constructional products shows a net cost saving. Assuming an average net recycling cost of building profiles, windows and pipes of about € 250/tonne, diversion from incineration would avoid € 165/tonne in incineration charges plus a further € 165/tonne in ‘incinerator subsidy’, making a net saving of € 80/tonne. In the case of flexible flooring, the net recycling cost is estimated to average € 350/tonne, the incinerator charge remains unchanged at € 165/tonne and the avoided ‘subsidy’ is € 85/tonne. The diversion of this product from incineration to recycling therefore incurs an additional cost of € 100/tonne. For the remaining products and applications, net costs of recycling are expected to be considerably greater than for rigid and flexible construction products, so therefore the net costs of diversion to recycling will be greater.

12. In the case of scenario 3, incineration costs (charges and ‘subsidy’) are exchanged for landfill costs, plus an additional cost element for sorting constructional PVC wastes for diversion from incineration to landfill. The cost of this additional sorting element is expected to be minimal, since it should be incorporated into the segregation of non-masonry constructional waste needed to increase the production of secondary aggregates from construction and demolition waste. Assuming a notional € 30/tonne as the cost of this additional sorting step, diverting PVC construction waste from incineration to landfill will result in a net cost saving of € 35/tonne (excluding the ‘incinerator subsidy’) or € 120/tonne (flexible PVC) to € 200/tonne (rigid PVC) with the ‘subsidy’.

13. The financial costs of the scenarios have been evaluated, taking account of the types of products involved and the relative amounts diverted from incineration and landfill. The results are shown in Table 57 as present value total costs over the twenty year horizon (at 4 per cent discount rate), annualised costs and costs per tonne of waste diverted.

Table 57: Present value financial costs for the EU-21 of diverting PVC (4% discount rate). Negative figures represent savings. The ranges correspond with the results for the high and low incineration futures investigated for the scenarios.

4% discount rate	Scenario 1	Scenario 2	Scenario 3
Average total PVC waste diverted, million tonnes2000-2020	**4.5 to recycling**	**9.76 to recycling**	**9.6-11.0 to landfill**
From landfill	**2.68-2.91**	**5.7-6.22**	**-**
From incineration	**1.60-1.83**	**3.55-4.07**	**9.6-11.0**
Total costs, million €			
Excluding 'incinerator subsidy'	372 to 381	2,179 to 2,200	-203 to -235
Including 'incinerator subsidy'	199 to 230	1,839 to 1,903	-882 to –1,019
Annualised costs, million € /year			
Excluding 'incinerator subsidy'	27 to 28	160 to 162	-15 to -17
Including 'incinerator subsidy'	15 to 17	135 to 140	-65 to -75
Cost per tonne diverted € /tonne			
Excluding 'incinerator subsidy'	82 to 84	223 to 225	-21
Including 'incinerator subsidy'	44 to 51	188 to 194	-92

14. The major source of uncertainty in the analysis is in the net cost of recycling. Cost estimates are subject to considerable uncertainty because of the very limited number of operational PVC recycling facilities for which data are available. This is particularly true of non-constructional applications of PVC which play a significant part in scenario 2. Diversion of constructional PVC waste from incineration to landfill under scenario 3 would result in net cost savings, although changes to proposed and existing legislation would be required to allow this scenario to develop.

15. The analysis has also considered the *environmental* costs to society, expressed in monetary terms to the extent possible, of altering the pattern of PVC waste management. Quantitative valuations of externalities have been obtained for emissions to air. The largest source of externalities is NO_x SO_2 CO_2 PM_{10} from virgin compound manufacture, followed by incineration (including a minor contribution from the manufacture of APC reagents). The externalities associated with air emissions of dioxins, cadmium and lead, and with electricity generation (assuming that the marginal technology is gas-fired combined cycle gas turbine plant over the period of interest here) have also been calculated.

16. Externality data are prone to significant uncertainty, and hence low and high estimates have been made to go alongside what we regard as the best estimates. The best estimates take a figure of €19 /tonne of CO_2 for climate change damages, include chronic effects of particle exposure on mortality, and value mortality linked to emissions of PM_{10}, SO_2 and NO_x using the more conservative value of life years

approach. Other uncertainties are assessed, but are far less important to the final conclusions of the study. For the low estimate a lower figure is taken for global warming damages, and chronic effects on mortality are excluded. The upper estimate is based on a higher estimate for global warming, inclusion of chronic effects of particle exposure on mortality and application of the value of statistical life approach for mortality linked to all effects considered here. The result is that the ranges for external cost data are extremely broad, greater than an order of magnitude from low to high, as the results in Table 58 demonstrate.

Table 58: Present value environmental externalities for the EU-21 of diverting PVC (4% discount rate). Negative figures represent benefits. Since the differences between the high and low incineration futures were negligible, results are shown here as averages.

	Scenario 1	**Scenario 2**	**Scenario 3**
Waste diverted, million tonnes2000-2020	**4.5 to recycling**	**9.76 to recycling**	**9.6-11 from incineration to landfill**
Total costs, million €			
Low	-112	-184	-121
Best estimate	-847	-1389	-529
High	-3123	-5271	-2569
Annualised costs, million €/year			
Low	-8	-14	-9
Best estimate	-62	-102	-39
High	-230	-388	-189
Cost per tonne of waste diverted, € /tonne			
Low	-25	-19	-12
Best estimate	-188	-142	-51
High	-693	-540	-249

17. The environmental analysis shows that for 'best' and 'high' valuations of externalities, the environmental benefits are sufficient to outweigh the financial costs of scenario 1, (compare Table 57 and Table 58), even when the avoided 'incinerator subsidy' is excluded from the financial costs. However, for scenario 2, only when the 'high' valuation of externalities is adopted do the environmental benefits exceed the financial cost of the scenarios. Scenario 3 shows a net cost saving in both financial and environmental terms.

18. It is necessary to ask how the numerous externalities that are omitted from this analysis would affect the final result – would they promote the case of incineration or not? It looks likely that most would increase the benefits of the diversion of material from incineration. One exception relates to the fate of phthalate plasticisers which are destroyed by incineration. Landfilled PVC would form a reservoir of these chemicals that could slowly leach out over time. The consequences of this are then dependent on the efficiency of leachate collection and treatment, proximity to drinking water supplies, etc.

19. Overall, we conclude that it is likely that there will be benefits to be gained from diverting PVC away from incineration, particularly to recycling, though there are

clearly very finite limits to what can be recycled. There are also limits on the economic limits for separation of PVC mingled with other types of waste. Whatever the future for PVC this problem will remain with us for many years as a consequence of the large stock of long-lived PVC products currently in use throughout Europe.

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APPENDICES

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Appendix 1.
Waste arisings by product categories.

The data on available post-consumer PVC waste arisings in this Appendix are based on estimates provided by EuPC.

Post consumerPVC waste categories given by EuPC

Flexible/rigid	Product	Product application	Ref No
F	Cables	Cables domestic installations	1
F	Films plastisiced	Films for building applications	2
F	Floor	Flooring paste based	3
F	Floor	Floor, calendered	4
F	Hoses and profiles	Building profiles and hoses	5
F	Coatings	Wall-paper, PVC foamed	6
F	Coatings	Wall-paper, PVC compact	7
F	Coatings	Air-inflated structures,containers,Marquees	8
F	Coatings	Roof coverings, paste	9
F	Organo-,Plastisols	Varnishes - coil coating	10
R	Rigid films	Pipe insulation film	11
R	Sheets	sheets for buildg. applications	12
R	Pipes and fittings	Pipes	13
R	Windowprofiles	Profiles for windows	14
R	Other profiles	Profiles for other building applic.	15
R	Other profiles	Profiles for cable ducts	16
F	Cables	Cables for e&e	10
F	Films plastisiced	Insulation & adhesive tapes	11
F	Hoses and profiles	profiles and hoses for electrical	12
F	Other plast.conv.	Inject.moulding a.o.elec.applications	13
R	Other profiles	Electrical appliances	14
F	Cables	Cars cables	15
F	Films plastisiced	Instrument panels a.o.films	16
F	Films plastisiced	Cabletapes and cablebinders	17
F	Hoses and profiles	Cars hoses & profiles	18
F	Coatings	Foamed films / artificial leather	19
F	Coatings	Tarpaulins for lorries	20
F	Organo-,Plastisols	Underfloor protection	21
F	Other plast.conv.	Others, injection moulding for cars	22
R	Other profiles	profiles for cars	23
R	Others	Battery separators	24
F	Films plastisiced	Agriculture	25
F	Organo-,Plastisols	Dipped products	26
F	Films plastisiced	Blood and infusion bags	27
F	Hoses and profiles	Medical hoses	28
F	Films plastisiced	Furniture	29
F	Hoses and profiles	Furniture profiles	30
R	Rigid films	Furniture, kitchens	31
R	Rigid films	Frames for drawers	32
R	Other profiles	Furniture other applications	33
F	Films plastisiced	Bags, luggage a. cushions	34
F	Films plastisiced	Officesupply, books, photogr.articles	35
F	Films plastisiced	Camping, leisure, toys, sport	36
F	Films plastisiced	miscellaneous plastisiced films	37
F	Hoses and profiles	Garden hoses	38
F	Hoses and profiles	Drinking hoses	39
F	Hoses and profiles	Other industrial hoses	40
F	Hoses and profiles	Other profiles	41
F	Coatings	Artificial leather (not car)	42
F	Coatings	Conveyor belts	43
F	Coatings	miscellaneous coatings	44
F	Organo-,Plastisols	Rotational mouldings	45
F	Organo-,Plastisols	Slush mouldings	46
F	Organo-,Plastisols	miscellaneous organosols a. plastis.	47
F	Other plast.conv.	shoes, soles	48
F	Other plast.conv.	miscellaneous (fibres etc.)	49
R	Rigid films	Office supply	50
R	Rigid films	Printed films	51
R	Rigid films	Credit cards	52
R	Rigid films	Diskettes	53
R	Rigid films	Other technical applications	54
R	Sheets	Chemical apparatus	55
R	Sheets	Miscellaneous sheet products	56
R	Other profiles	Miscellaneous	57
R	Gramophone	Gramophone records	58
R	Other rigid	Other rigid products	59
F	Films plastisiced	Packaging-wrapping a.other films	60
F	Organols-,Plastisols	Cans	61
R	Rigid films	Rigid films	62
R	For bottles	Bottles	63

AEA product categories

The contribution of each category to the total arisings for 2000 is indicated, based on EuPC data.
The categories used here were obtained by aggregating data from the information provided by EuPC.

Waste stream	PVC type	Product	2000	EuPC product ref	Note
Construction	Flexible	Cables	0.83%	1	
Construction	Flexible	Flooring, calendered	5.85%	4	
Construction	Flexible	Profiles and hoses	3.51%	5	
Construction	Flexible	Other flexible construction products	13.52%	2,3,6,7,8,9 &10	
Construction	Rigid	Pipes	1.63%	13	
Construction	Rigid	Window profiles	1.26%	14	
Construction	Rigid	Profiles - cable trays	0.20%	16	
Construction	Rigid	Other profiles	4.68%	15	
Construction	Rigid	Other rigid construction products	0.16%	11&12	
Packaging	Flexible	Various flexible products	1.56%	60&61	
Packaging	Rigid	Bottles	7.08%	63	
Packaging	Rigid	Other rigid packaging products	8.09%	62	
Household and commercial products	Flexible	Shoe soles	2.18%	48	
Household and commercial products	Flexible	Various flexible products	17.54%	29,30, 34-47, 49	A
Household and commercial products	Rigid	Printed films	0.74%	51	
Household and commercial products	Rigid	Sheets, chemical equipment	0.22%	55	
Household and commercial products	Rigid	Miscellaneous sheets	0.78%	56	
Household and commercial products	Rigid	Miscellaneous rigid profiles	1.23%	59	
Household and commercial products	Rigid	Credit cards	0.67%	52	
Household and commercial products	Rigid	Other rigid products	2.84%	31-33, 50, 53, 54, 57,58	B
Electrical and electronics	Flexible	Cables	6.43%	10	
Electrical and electronics	Flexible	Adhesive tapes	1.09%	11	
Electrical and electronics	Flexible	Injection moulded parts	1.15%	13	
Electrical and electronics	Flexible	Various flexible products	0.29%	12	
Electrical and electronics	Rigid	Various rigid products	0.08%	14	
Automotive	Flexible	Various flexible products	14.36%	15-22	
Automotive	Rigid	Various rigid products	0.39%	23,24	
Other products*	Flexible	Various flexible products	1.66%	25-28	
		Total	**100.00%**		

*NB there were no rigid products in the 'Other' application category

The combined product types A and B used in this study were wider than those used in the mechanical recycling project
In the case of group A, the recycling study found that only EuPC product ref 49 was a candidate for high quality mechanical recycling, for which a recycling potential of 5-15 per cent (chosen value 10 per cent) was estimated. This product type accounts for only 8.7 to 11.7 per cent (from 2000 to 2020) of the category shown as 'Miscelaneous F' in Table 4. The potential recycling rate given in Table 4 for this application/product group must therefore be scaled down by this proportion in estimating the true recycling rate. This correction has been applied in the analysis. A similar consideration also applies to the category noted at B, 'other rigid products'. The potential recycling rate in this case has been reduced by 20 to 32 per cent (2000-2020) of the potential shown in Table 4.

Waste destinations (BAU) - Construction waste

Arisings

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	30	41	56	75	91	1,166
F	Flooring, calendered	209	250	285	318	331	5,616
F	Profiles and hoses	126	129	125	127	122	2,523
F	Other flexible construction products	484	513	567	641	691	11,547
R	Pipes	58	91	133	191	253	2,851
R	Window profiles	45	76	124	198	287	2,823
R	Profiles - cable trays	7	12	19	29	40	415
R	Other profiles	168	256	352	461	556	7,155
R	Other rigid construction products	6	9	14	21	28	305

High Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	1	3	8	12	15	154
F	Flooring, calendered	13	54	97	119	134	1,720
F	Profiles and hoses	8	30	49	54	57	827
F	Other flexible construction products	30	120	221	275	320	3,955
R	Pipes	3	17	38	61	87	806
R	Window profiles	2	12	30	52	82	682
R	Profiles - cable trays	0	3	7	12	19	160
R	Other profiles	10	60	137	198	258	2,643
R	Other rigid construction products	0	2	6	9	13	116

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	10	11	12	15	18	265
F	Flooring, calendered	191	177	152	159	155	3,309
F	Profiles and hoses	118	99	76	72	66	1,696
F	Other flexible construction products	454	393	347	366	371	7,592
R	Pipes	49	57	60	81	100	1,364
R	Window profiles	35	41	47	69	95	1,110
R	Profiles - cable trays	7	9	11	16	22	255
R	Other profiles	157	196	215	263	298	4,511
R	Other rigid construction products	5	7	9	12	15	189
		1,027				1,139	

Recycling

	Construction wastes	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	19	27	36	48	58	746		746
F	Flooring, calendered	5	19	36	40	41	587	587	
F	Profiles and hoses								
F	Other flexible construction products								
R	Pipes	6	16	35	50	66	681	681	
R	Window profiles	7	23	48	76	111	1,031	1,031	
R	Profiles - cable trays								
R	Other profiles								
R	Other rigid construction products								

Low Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	1	3	7	10	13	134
F	Flooring, calendered	13	42	84	105	119	1,484
F	Profiles and hoses	8	23	42	48	50	712
F	Other flexible construction products	30	93	191	241	284	3,415
R	Pipes	3	14	33	53	77	700
R	Window profiles	2	10	26	46	73	594
R	Profiles - cable trays	0	2	6	11	17	139
R	Other profiles	10	46	119	174	229	2,292
R	Other rigid construction products	0	2	5	8	12	101

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	10	12	13	17	19	286
F	Flooring, calendered	191	189	165	174	170	3,545
F	Profiles and hoses	118	105	83	79	72	1,811
F	Other flexible construction products	454	420	376	400	407	8,132
R	Pipes	49	61	65	88	110	1,470
R	Window profiles	35	44	51	76	104	1,199
R	Profiles - cable trays	7	10	12	18	24	276
R	Other profiles	157	209	233	287	327	4,862
R	Other rigid construction products	5	8	9	13	16	204

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	37	85	154	214	276	3,045	**2298**	**746**
Incineration (high incin future)	68	302	592	792	984	11,064		
Landfill (high incin future)	1,027	991	929	1,055	1,139	20,292		
Incineration (low incin future)	68	234	513	696	874	9,571		
Landfill (low incin future)	1,027	1,059	1,009	1,151	1,250	21,785		
Total waste accounted for (high)	1,132	1,377	1,676	2,061	2,399	34,400		
Total waste accounted for (low)	1,132	1,377	1,676	2,061	2,399	34,400		
Totals from PVC model	1,132	1,377	1,676	2,061	2,399	34,400		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario 1) - Construction waste

Arisings

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	30	41	56	75	91	1,166
F	Flooring, calendered	209	250	285	318	331	5,616
F	Profiles and hoses	126	129	125	127	122	2,523
F	Other flexible construction products	484	513	567	641	691	11,547
R	Pipes	58	91	133	191	253	2,851
R	Window profiles	45	76	124	198	287	2,823
R	Profiles - cable trays	7	12	19	29	40	415
R	Other profiles	168	256	352	461	556	7,155
R	Other rigid construction products	6	9	14	21	28	305

High Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	1	3	8	12	15	154
F	Flooring, calendered	13	50	83	102	115	1,499
F	Profiles and hoses	8	30	49	54	57	827
F	Other flexible construction products	30	120	221	275	320	3,955
R	Pipes	3	13	18	29	41	411
R	Window profiles	2	12	22	38	60	515
R	Profiles - cable trays	0	2	4	7	11	99
R	Other profiles	10	48	82	119	155	1,656
R	Other rigid construction products	0	2	6	9	13	116

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	10	11	12	15	18	265
F	Flooring, calendered	191	165	130	136	133	2,972
F	Profiles and hoses	118	99	76	72	66	1,696
F	Other flexible construction products	454	393	347	366	371	7,592
R	Pipes	49	43	28	38	47	792
R	Window profiles	35	39	34	51	69	883
R	Profiles - cable trays	7	7	7	10	13	169
R	Other profiles	157	157	129	158	179	3,060
R	Other rigid construction products	5	7	9	12	15	189

Low Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	1	3	7	10	13	134
F	Flooring, calendered	13	39	72	90	102	1,292
F	Profiles and hoses	8	23	42	48	50	712
F	Other flexible construction products	30	93	191	241	284	3,415
R	Pipes	3	10	16	25	36	355
R	Window profiles	2	9	19	34	53	447
R	Profiles - cable trays	0	2	4	6	10	86
R	Other profiles	10	37	71	104	137	1,432
R	Other rigid construction products	0	2	5	8	12	101

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	10	12	13	17	19	286
F	Flooring, calendered	191	177	142	149	146	3,178
F	Profiles and hoses	118	105	83	79	72	1,811
F	Other flexible construction products	454	420	376	400	407	8,132
R	Pipes	49	46	31	42	52	848
R	Window profiles	35	42	37	55	76	951
R	Profiles - cable trays	7	8	7	11	14	182
R	Other profiles	157	167	140	172	196	3,284
R	Other rigid construction products	5	8	9	13	16	204

Recycling

	Construction wastes	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	19	27	36	48	58	746		746
F	Flooring, calendered	5	34	71	80	83	1,146	1,146	
F	Profiles and hoses	0	0	0	0	0	0	0	
F	Other flexible construction products	0	0	0	0	0	0		
R	Pipes	6	34	87	124	164	1,649	1,649	
R	Window profiles	7	25	68	109	158	1,425	1,425	
R	Profiles - cable trays	0	2	7	12	16	147	147	
R	Other profiles	0	51	141	184	223	2,439	2,439	
R	Other rigid construction products	0	0	0	0	0	0		

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	37	174	410	557	702	7,551	**6805**	**746**
Incineration (high incin future)	68	281	493	645	787	9,232		
Landfill (high incin future)	1,027	922	773	859	911	17,617		
Incineration (low incin future)	68	218	427	567	699	7,974		
Landfill (low incin future)	1,027	986	839	938	999	18,875		
Total waste accounted for (high)	1,132	1,377	1,676	2,061	2,399	34,400		
Total waste accounted for (low)	1,132	1,377	1,676	2,061	2,399	34,400		
Totals from PVC model	1,132	1,377	1,676	2,061	2,399	34,400		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario2) - Construction waste

Arisings

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	30	41	56	75	91	1,166
F	Flooring, calendered	209	250	285	318	331	5,616
F	Profiles and hoses	126	129	125	127	122	2,523
F	Other flexible construction products	484	513	567	641	691	11,547
R	Pipes	58	91	133	191	253	2,851
R	Window profiles	45	76	124	198	287	2,823
R	Profiles - cable trays	7	12	19	29	40	415
R	Other profiles	168	256	352	461	556	7,155
R	Other rigid construction products	6	9	14	21	28	305

High Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	1	3	2	3	4	52
F	Flooring, calendered	13	49	78	96	107	1,410
F	Profiles and hoses	8	26	37	41	43	644
F	Other flexible construction products	30	120	221	275	320	3,955
R	Pipes	3	13	16	25	35	359
R	Window profiles	2	11	19	34	53	462
R	Profiles - cable trays	0	2	4	6	9	84
R	Other profiles	10	45	69	99	129	1,409
R	Other rigid construction products	0	2	6	9	13	116

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	8	9	3	4	5	115
F	Flooring, calendered	190	160	122	127	124	2,832
F	Profiles and hoses	118	86	57	54	49	1,407
F	Other flexible construction products	454	393	347	366	371	7,592
R	Pipes	49	41	24	33	41	716
R	Window profiles	35	38	30	45	62	806
R	Profiles - cable trays	7	7	6	8	11	147
R	Other profiles	157	147	108	132	149	2,697
R	Other rigid construction products	5	7	9	12	15	189

Recycling

	Construction wastes	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	21	30	51	68	82	999		999
F	Flooring, calendered	6	41	85	96	99	1,375	1,375	
F	Profiles and hoses	0	16	31	32	31	472	472	
F	Other flexible construction products	0	0	0	0	0	0		
R	Pipes	6	37	93	134	177	1,776	1,776	
R	Window profiles	8	28	75	119	172	1,555	1,555	
R	Profiles - cable trays	0	3	9	14	20	184	184	
R	Other profiles	0	64	176	231	278	3,048	3,048	
R	Other rigid construction products	0	0	0	0	0	0		

Low Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	1	2	2	3	4	45
F	Flooring, calendered	13	38	67	84	95	1,215
F	Profiles and hoses	8	20	32	36	38	553
F	Other flexible construction products	30	93	191	241	284	3,415
R	Pipes	3	10	13	22	31	310
R	Window profiles	2	9	17	30	47	401
R	Profiles - cable trays	0	2	3	5	8	73
R	Other profiles	10	35	59	87	114	1,217
R	Other rigid construction products	0	2	5	8	12	101

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	8	9	4	5	5	122
F	Flooring, calendered	190	171	132	139	136	3,026
F	Profiles and hoses	118	92	62	59	54	1,498
F	Other flexible construction products	454	420	376	400	407	8,132
R	Pipes	49	44	26	36	45	765
R	Window profiles	35	40	33	49	68	867
R	Profiles - cable trays	7	7	6	9	12	158
R	Other profiles	157	157	117	144	164	2,889
R	Other rigid construction products	5	8	9	13	16	204

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	42	218	521	692	859	9,408	**8409**	**999**
Incineration (high incin future)	68	271	450	587	714	8,492		
Landfill (high incin future)	1,022	888	706	782	826	16,501		
Incineration (low incin future)	68	210	389	516	634	7,330		
Landfill (low incin future)	1,022	949	766	853	906	17,663		
Total waste accounted for (high)	1,132	1,377	1,676	2,061	2,399	34,400		
Total waste accounted for (low)	1,132	1,377	1,676	2,061	2,399	34,400		
Totals from PVC model	1,132	1,377	1,676	2,061	2,399	34,400		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario3) - Construction waste

Arisings

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	30	41	56	75	91	1,166
F	Flooring, calendered	209	250	285	318	331	5,616
F	Profiles and hoses	126	129	125	127	122	2,523
F	Other flexible construction products	484	513	567	641	691	11,547
R	Pipes	58	91	133	191	253	2,851
R	Window profiles	45	76	124	198	287	2,823
R	Profiles - cable trays	7	12	19	29	40	415
R	Other profiles	168	256	352	461	556	7,155
R	Other rigid construction products	6	9	14	21	28	305

High Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables						
F	Flooring, calendered						
F	Profiles and hoses						
F	Other flexible construction products						
R	Pipes						
R	Window profiles						
R	Profiles - cable trays						
R	Other profiles						
R	Other rigid construction products						

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	11	15	20	27	33	420
F	Flooring, calendered	204	231	249	279	289	5,029
F	Profiles and hoses	126	129	125	127	122	2,523
F	Other flexible construction products	484	513	567	641	691	11,547
R	Pipes	53	75	99	141	187	2,170
R	Window profiles	38	53	76	122	177	1,793
R	Profiles - cable trays	7	12	19	29	40	415
R	Other profiles	168	256	352	461	556	7,155
R	Other rigid construction products	6	9	14	21	28	305

Recycling

	Construction wastes	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	19	27	36	48	58	746		746
F	Flooring, calendered	5	19	36	40	41	587	587	
F	Profiles and hoses								
F	Other flexible construction products								
R	Pipes	6	16	35	50	66	681	681	
R	Window profiles	7	23	48	76	111	1,031	1,031	
R	Profiles - cable trays								
R	Other profiles								
R	Other rigid construction products								

Low Incineration future

Incineration

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables						
F	Flooring, calendered						
F	Profiles and hoses						
F	Other flexible construction products						
R	Pipes						
R	Window profiles						
R	Profiles - cable trays						
R	Other profiles						
R	Other rigid construction products						

Landfill

	Construction wastes	2000	2005	2010	2015	2020	Cum
F	Cables	11	15	20	27	33	420
F	Flooring, calendered	204	231	249	279	289	5,029
F	Profiles and hoses	126	129	125	127	122	2,523
F	Other flexible construction products	484	513	567	641	691	11,547
R	Pipes	53	75	99	141	187	2,170
R	Window profiles	38	53	76	122	177	1,793
R	Profiles - cable trays	7	12	19	29	40	415
R	Other profiles	168	256	352	461	556	7,155
R	Other rigid construction products	6	9	14	21	28	305

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	37	85	154	214	276	3,045	**2298**	**746**
Incineration (high incin future)								
Landfill (high incin future)	1,095	1,293	1,522	1,847	2,124	31,356		
Incineration (low incin future)								
Landfill (low incin future)	1,095	1,293	1,522	1,847	2,124	31,356		
Total waste accounted for (high)	1,132	1,377	1,676	2,061	2,399	34,400		
Total waste accounted for (low)	1,132	1,377	1,676	2,061	2,399	34,400		
Totals from PVC model	1,132	1,377	1,676	2,061	2,399	34,400		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (BAU) - Packaging waste

Arisings

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	56	56	57	61	63	1,166
R	Bottles	254	137	76	44	25	1,978
R	Other rigid packaging products	290	332	386	464	536	7,977

High Incineration future

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	20	24	28	33	481
R	Bottles	67	48	32	20	13	699
R	Other rigid packaging products	80	102	129	173	224	2,781

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	37	33	32	30	685
R	Bottles	166	89	44	23	12	1,228
R	Other rigid packaging products	198	191	180	198	205	3,849

Recycling

	Packaging waste	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Bottles	20					51	51	
R	Other rigid packaging products	12	40	77	93	107	1,347		1,347

Low Incineration future

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	18	21	25	29	435
R	Bottles	67	44	28	18	12	647
R	Other rigid packaging products	80	94	113	154	201	2,510

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	38	36	36	33	732
R	Bottles	166	93	48	26	13	1,280
R	Other rigid packaging products	198	198	196	217	228	4,120

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	32	40	77	93	107	1,397	**51**	**1347**
Incineration (high incin future)	164	169	185	222	269	3,962		
Landfill (high incin future)	403	317	257	254	247	5,762		
Incineration (low incin future)	164	156	162	197	242	3,592		
Landfill (low incin future)	403	329	280	278	274	6,132		
Total waste accounted for (high)	599	525	519	569	624	11,121		
Total waste accounted for (low)	599	525	519	569	624	11,121		
Totals from PVC model	599	525	519	569	624	11,121		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario1) - Packaging Waste

Arisings

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	56	56	57	61	63	1,166
R	Bottles	254	137	76	44	25	1,978
R	Other rigid packaging products	290	332	386	464	536	7,977

High Incineration future

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	20	24	28	33	481
R	Bottles	67	48	32	20	13	699
R	Other rigid packaging products	80	102	129	173	224	2,781

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	37	33	32	30	685
R	Bottles	166	89	44	23	12	1,228
R	Other rigid packaging products	198	191	180	198	205	3,849

Low Incineration future

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	18	21	25	29	435
R	Bottles	67	44	28	18	12	647
R	Other rigid packaging products	80	94	113	154	201	2,510

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	38	36	36	33	732
R	Bottles	166	93	48	26	13	1,280
R	Other rigid packaging products	198	198	196	217	228	4,120

Recycling

	Packaging waste	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Bottles	20					51	51	
R	Other rigid packaging products	12	40	77	93	107	1,347		1,347

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	32	40	77	93	107	1,397	**51**	**1347**
Incineration (high incin future)	164	169	185	222	269	3,962		
Landfill (high incin future)	403	317	257	254	247	5,762		
Incineration (low incin future)	164	156	162	197	242	3,592		
Landfill (low incin future)	403	329	280	278	274	6,132		
Total waste accounted for (high)	599	525	519	569	624	11,121		
Total waste accounted for (low)	599	525	519	569	624	11,121		
Totals from PVC model	599	525	519	569	624	11,121		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario2) - Packaging Waste

Arisings

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	56	56	57	61	63	1,166
R	Bottles	254	137	76	44	25	1,978
R	Other rigid packaging products	290	332	386	464	536	7,977

High Incineration future

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	20	24	28	33	481
R	Bottles	67	48	32	20	13	698
R	Other rigid packaging products	80	98	121	163	210	2,632

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	37	33	32	30	685
R	Bottles	164	89	44	23	12	1,223
R	Other rigid packaging products	196	184	169	186	193	3,661

Recycling

	Packaging waste	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Bottles	23					57	57	
R	Other rigid packaging products	14	50	97	116	134	1,683		1,683

Low Incineration future

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	18	21	25	29	435
R	Bottles	67	44	28	18	12	645
R	Other rigid packaging products	80	91	106	144	189	2,377

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	38	36	36	33	732
R	Bottles	164	93	48	26	13	1,275
R	Other rigid packaging products	196	192	184	204	213	3,917

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	37	50	97	116	134	1,740	**57**	**1683**
Incineration (high incin future)	162	166	177	211	255	3,811		
Landfill (high incin future)	399	310	246	241	234	5,570		
Incineration (low incin future)	162	153	154	188	230	3,457		
Landfill (low incin future)	399	323	268	265	260	5,924		
Total waste accounted for (high)	599	525	519	569	624	11,121		
Total waste accounted for (low)	599	525	519	569	624	11,121		
Totals from PVC model	599	525	519	569	624	11,121		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario3) - Packaging Waste

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	20	24	28	33	481
R	Bottles	67	48	32	20	13	699
R	Other rigid packaging products	80	102	129	173	224	2,781

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	37	33	32	30	685
R	Bottles	166	89	44	23	12	1,228
R	Other rigid packaging products	198	191	180	198	205	3,849

High Incineration future

Arisings

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	56	56	57	61	63	1,166
R	Bottles	254	137	76	44	25	1,978
R	Other rigid packaging products	290	332	386	464	536	7,977

Recycling

	Packaging waste	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Bottles	20					51	51	
R	Other rigid packaging products	12	40	77	93	107	1,347		1,347

Incineration

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	16	18	21	25	29	435
R	Bottles	67	44	28	18	12	647
R	Other rigid packaging products	80	94	113	154	201	2,510

Landfill

	Packaging waste	2000	2005	2010	2015	2020	Cum
F	Various flexible products	40	38	36	36	33	732
R	Bottles	166	93	48	26	13	1,280
R	Other rigid packaging products	198	198	196	217	228	4,120

Low Incineration future

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	32	40	77	93	107	1,397	**51**	**1347**
Incineration (high incin future)	164	169	185	222	269	3,962		
Landfill (high incin future)	403	317	257	254	247	5,762		
Incineration (low incin future)	164	156	162	197	242	3,592		
Landfill (low incin future)	403	329	280	278	274	6,132		
Total waste accounted for (high)	599	525	519	569	624	11,121		
Total waste accounted for (low)	599	525	519	569	624	11,121		
Totals from PVC model	599	525	519	569	624	11,121		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (BAU) - Household and commercial waste

Arisings

	H&C	2000	2005	2010	2015	2020	Cum
F	Shoe soles	78	86	96	109	118	1,948
F	Various flexible products	628	691	766	897	1,022	15,893
R	Printed films	26	34	43	56	70	908
R	Sheets, chemical equipment	8	13	20	33	44	458
R	Miscellaneous sheets	28	34	39	48	55	814
R	Miscellaneous rigid profiles	44	52	70	96	126	1,513
R	Credit cards	24	46	89	174	326	2,421
R	Other rigid products	102	141	191	257	326	4,015

High Incineration future

Incineration

	H&C	2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	31	41	53	64	809
F	Various flexible products	81	250	327	432	552	6,632
R	Printed films	3	12	18	27	38	393
R	Sheets, chemical equipment	1	5	9	16	24	207
R	Miscellaneous sheets	4	12	17	23	30	344
R	Miscellaneous rigid profiles	6	19	30	46	68	659
R	Credit cards	3	17	38	84	176	1,141
R	Other rigid products	13	51	82	124	176	1,756

Landfill

	H&C	2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	55	55	57	54	1,138
F	Various flexible products	547	440	438	465	470	9,261
R	Printed films	23	22	25	29	32	516
R	Sheets, chemical equipment	7	8	12	17	20	251
R	Miscellaneous sheets	24	22	23	25	25	470
R	Miscellaneous rigid profiles	38	33	40	50	58	854
R	Credit cards	21	29	51	90	150	1,280
R	Other rigid products	88	90	110	133	150	2,259

Recycling

	H&C	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Shoe soles								
F	Various flexible products								
R	Printed films								
R	Sheets, chemical equipment								
R	Miscellaneous sheets								
R	Miscellaneous rigid profiles								
R	Credit cards								
R	Other rigid products								

Low Incineration future

Incineration

	H&C	2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	22	36	47	58	695
F	Various flexible products	81	178	287	385	499	5,704
R	Printed films	3	9	16	24	34	340
R	Sheets, chemical equipment	1	3	8	14	21	181
R	Miscellaneous sheets	4	9	15	20	27	297
R	Miscellaneous rigid profiles	6	13	26	41	62	572
R	Credit cards	3	12	33	75	159	1,006
R	Other rigid products	13	36	72	110	159	1,523

Landfill

	H&C	2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	64	60	62	60	1,253
F	Various flexible products	547	513	478	512	523	10,189
R	Printed films	23	25	27	32	36	568
R	Sheets, chemical equipment	7	9	13	19	22	277
R	Miscellaneous sheets	24	25	25	27	28	517
R	Miscellaneous rigid profiles	38	38	43	55	65	941
R	Credit cards	21	34	55	99	167	1,415
R	Other rigid products	88	105	119	147	167	2,492

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	122	397	562	804	1,129	11,941		
Landfill (high incin future)	817	699	752	866	960	16,028		
Incineration (low incin future)	122	282	493	717	1,020	10,317		
Landfill (low incin future)	817	814	821	953	1,068	17,652		
Total waste accounted for (high)	938	1,097	1,314	1,670	2,088	27,969		
Total waste accounted for (low)	938	1,097	1,314	1,670	2,088	27,969		
Totals from PVC model	938	1,097	1,314	1,670	2,088	27,969		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario1) - Household and commercial waste

Arisings

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	78	86	96	109	118	1,948
F	Various flexible products	628	691	766	897	1,022	15,893
R	Printed films	26	34	43	56	70	908
R	Sheets, chemical equipment	8	13	20	33	44	458
R	Miscellaneous sheets	28	34	39	48	55	814
R	Miscellaneous rigid profiles	44	52	70	96	126	1,513
R	Credit cards	24	46	89	174	326	2,421
R	Other rigid products	102	141	191	257	326	4,015

High Incineration future

Incineration

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	31	41	53	64	809
F	Various flexible products	81	250	327	432	552	6,632
R	Printed films	3	12	18	27	38	393
R	Sheets, chemical equipment	1	5	9	16	24	207
R	Miscellaneous sheets	4	12	17	23	30	344
R	Miscellaneous rigid profiles	6	19	30	46	68	659
R	Credit cards	3	17	38	84	176	1,141
R	Other rigid products	13	51	82	124	176	1,756

Landfill

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	55	55	57	54	1,138
F	Various flexible products	547	440	438	465	470	9,261
R	Printed films	23	22	25	29	32	516
R	Sheets, chemical equipment	7	8	12	17	20	251
R	Miscellaneous sheets	24	22	23	25	25	470
R	Miscellaneous rigid profiles	38	33	40	50	58	854
R	Credit cards	21	29	51	90	150	1,280
R	Other rigid products	88	90	110	133	150	2,259

Recycling

H&C		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Shoe soles								
F	Various flexible products								
R	Printed films								
R	Sheets, chemical equipment								
R	Miscellaneous sheets								
R	Miscellaneous rigid profiles								
R	Credit cards								
R	Other rigid products								

Low Incineration future

Incineration

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	22	36	47	58	695
F	Various flexible products	81	178	287	385	499	5,704
R	Printed films	3	9	16	24	34	340
R	Sheets, chemical equipment	1	3	8	14	21	181
R	Miscellaneous sheets	4	9	15	20	27	297
R	Miscellaneous rigid profiles	6	13	26	41	62	572
R	Credit cards	3	12	33	75	159	1,006
R	Other rigid products	13	36	72	110	159	1,523

Landfill

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	64	60	62	60	1,253
F	Various flexible products	547	513	478	512	523	10,189
R	Printed films	23	25	27	32	36	568
R	Sheets, chemical equipment	7	9	13	19	22	277
R	Miscellaneous sheets	24	25	25	27	28	517
R	Miscellaneous rigid profiles	38	38	43	55	65	941
R	Credit cards	21	34	55	99	167	1,415
R	Other rigid products	88	105	119	147	167	2,492

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	122	397	562	804	1,129	11,941		
Landfill (high incin future)	817	699	752	866	960	16,028		
Incineration (low incin future)	122	282	493	717	1,020	10,317		
Landfill (low incin future)	817	814	821	953	1,068	17,652		
Total waste accounted for (high)	938	1,097	1,314	1,670	2,088	27,969		
Total waste accounted for (low)	938	1,097	1,314	1,670	2,088	27,969		
Totals from PVC model	938	1,097	1,314	1,670	2,088	27,969		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario2) - Household and commercial Waste

Arisings

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	78	86	96	109	118	1,948
F	Various flexible products	628	691	766	897	1,022	15,893
R	Printed films	26	34	43	56	70	908
R	Sheets, chemical equipment	8	13	20	33	44	458
R	Miscellaneous sheets	28	34	39	48	55	814
R	Miscellaneous rigid profiles	44	52	70	96	126	1,513
R	Credit cards	24	46	89	174	326	2,421
R	Other rigid products	102	141	191	257	326	4,015

High Incineration future

Incineration

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	27	31	39	48	633
F	Various flexible products	81	249	323	425	543	6,541
R	Printed films	3	10	11	16	23	251
R	Sheets, chemical equipment	1	4	5	9	14	130
R	Miscellaneous sheets	4	10	10	14	18	223
R	Miscellaneous rigid profiles	6	17	24	37	55	539
R	Credit cards	3	17	38	84	176	1,141
R	Other rigid products	13	50	77	116	165	1,662

Landfill

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	48	41	42	41	931
F	Various flexible products	547	437	432	458	462	9,156
R	Printed films	23	17	15	18	19	354
R	Sheets, chemical equipment	7	6	7	10	12	166
R	Miscellaneous sheets	24	17	14	15	15	328
R	Miscellaneous rigid profiles	38	30	32	40	46	719
R	Credit cards	21	29	51	90	150	1,280
R	Other rigid products	88	88	103	125	140	2,153

Low Incineration future

Incineration

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	19	27	35	43	542
F	Various flexible products	81	177	283	379	491	5,624
R	Printed films	3	7	10	15	21	216
R	Sheets, chemical equipment	1	3	5	8	13	113
R	Miscellaneous sheets	4	7	9	12	16	190
R	Miscellaneous rigid profiles	6	12	21	33	49	467
R	Credit cards	3	12	33	75	159	1,006
R	Other rigid products	13	35	68	104	149	1,440

Landfill

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	56	45	47	45	1,022
F	Various flexible products	547	509	471	504	514	10,073
R	Printed films	23	20	16	19	22	389
R	Sheets, chemical equipment	7	8	8	11	13	183
R	Miscellaneous sheets	24	20	15	16	17	360
R	Miscellaneous rigid profiles	38	35	35	44	52	791
R	Credit cards	21	34	55	99	167	1,415
R	Other rigid products	88	102	113	138	156	2,375

Recycling

H&C		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Shoe soles		11	24	27	30	384	384	
F	Various flexible products		5	11	14	18	196	196	
R	Printed films		7	17	23	28	303	303	
R	Sheets, chemical equipment		3	8	13	18	162	162	
R	Miscellaneous sheets		7	16	19	22	263	263	
R	Miscellaneous rigid profiles		5	14	19	25	255	255	
R	Credit cards								
R	Other rigid products		3	11	15	21	200	200	

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling		40	101	131	161	1,764	**1764**	
Incineration (high incin future)	122	383	519	741	1,041	11,119		
Landfill (high incin future)	817	674	694	798	885	15,086		
Incineration (low incin future)	122	272	455	661	941	9,598		
Landfill (low incin future)	817	784	758	878	986	16,608		
Total waste accounted for (high)	938	1,097	1,314	1,670	2,088	27,969		
Total waste accounted for (low)	938	1,097	1,314	1,670	2,088	27,969		
Totals from PVC model	938	1,097	1,314	1,670	2,088	27,969		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario3) - Household and commercial Waste

Arisings

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	78	86	96	109	118	1,948
F	Various flexible products	628	691	766	897	1,022	15,893
R	Printed films	26	34	43	56	70	908
R	Sheets, chemical equipment	8	13	20	33	44	458
R	Miscellaneous sheets	28	34	39	48	55	814
R	Miscellaneous rigid profiles	44	52	70	96	126	1,513
R	Credit cards	24	46	89	174	326	2,421
R	Other rigid products	102	141	191	257	326	4,015

High Incineration future

Incineration

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	31	41	53	64	809
F	Various flexible products	81	250	327	432	552	6,632
R	Printed films	3	12	18	27	38	393
R	Sheets, chemical equipment	1	5	9	16	24	207
R	Miscellaneous sheets	4	12	17	23	30	344
R	Miscellaneous rigid profiles	6	19	30	46	68	659
R	Credit cards	3	17	38	84	176	1,141
R	Other rigid products	13	51	82	124	176	1,756

Landfill

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	55	55	57	54	1,138
F	Various flexible products	547	440	438	465	470	9,261
R	Printed films	23	22	25	29	32	516
R	Sheets, chemical equipment	7	8	12	17	20	251
R	Miscellaneous sheets	24	22	23	25	25	470
R	Miscellaneous rigid profiles	38	33	40	50	58	854
R	Credit cards	21	29	51	90	150	1,280
R	Other rigid products	88	90	110	133	150	2,259

Recycling

H&C		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Shoe soles								
F	Various flexible products								
R	Printed films								
R	Sheets, chemical equipment								
R	Miscellaneous sheets								
R	Miscellaneous rigid profiles								
R	Credit cards								
R	Other rigid products								

Low Incineration future

Incineration

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	10	22	36	47	58	695
F	Various flexible products	81	178	287	385	499	5,704
R	Printed films	3	9	16	24	34	340
R	Sheets, chemical equipment	1	3	8	14	21	181
R	Miscellaneous sheets	4	9	15	20	27	297
R	Miscellaneous rigid profiles	6	13	26	41	62	572
R	Credit cards	3	12	33	75	159	1,006
R	Other rigid products	13	36	72	110	159	1,523

Landfill

H&C		2000	2005	2010	2015	2020	Cum
F	Shoe soles	68	64	60	62	60	1,253
F	Various flexible products	547	513	478	512	523	10,189
R	Printed films	23	25	27	32	36	568
R	Sheets, chemical equipment	7	9	13	19	22	277
R	Miscellaneous sheets	24	25	25	27	28	517
R	Miscellaneous rigid profiles	38	38	43	55	65	941
R	Credit cards	21	34	55	99	167	1,415
R	Other rigid products	88	105	119	147	167	2,492

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	122	397	562	804	1,129	11,941		
Landfill (high incin future)	817	699	752	866	960	16,028		
Incineration (low incin future)	122	282	493	717	1,020	10,317		
Landfill (low incin future)	817	814	821	953	1,068	17,652		
Total waste accounted for (high)	938	1,097	1,314	1,670	2,088	27,969		
Total waste accounted for (low)	938	1,097	1,314	1,670	2,088	27,969		
Totals from PVC model	938	1,097	1,314	1,670	2,088	27,969		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (BAU) - Electrical and electronic waste

Arisings

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	230	276	325	390	427	6,597
F	Adhesive tapes	39	43	49	56	62	996
F	Injection moulded parts	41	47	55	65	74	1,123
F	Various flexible products	10	14	18	19	19	329
R	Various rigid products	3	4	5	7	8	107

High Incineration future

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	74	86	114	136	1,770
F	Adhesive tapes	4	12	13	16	20	265
F	Injection moulded parts	5	12	15	19	24	301
F	Various flexible products	1	5	7	8	9	125
R	Various rigid products	0	1	2	3	4	41

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	186	147	135	151	154	3,019
F	Adhesive tapes	32	23	20	22	22	462
F	Injection moulded parts	33	25	23	25	27	516
F	Various flexible products	9	10	11	11	10	204
R	Various rigid products	2	3	3	4	4	66

Recycling

	E&E	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	18	55	104	125	137	1,807		1,807
F	Adhesive tapes	3	9	16	18	20	269		269
F	Injection moulded parts	3	9	18	21	24	307		307
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	50	75	100	121	1,490
F	Adhesive tapes	4	8	11	14	18	223
F	Injection moulded parts	5	9	13	17	21	253
F	Various flexible products	1	3	6	7	8	105
R	Various rigid products	0	1	2	2	3	35

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	186	170	147	165	169	3,299
F	Adhesive tapes	32	27	22	24	25	504
F	Injection moulded parts	33	29	25	28	29	563
F	Various flexible products	9	11	12	12	11	224
R	Various rigid products	2	3	4	4	4	72

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	25	73	137	164	180	2,383		2383
Incineration (high incin future)	36	104	123	160	192	2,502		
Landfill (high incin future)	263	207	192	213	218	4,266		
Incineration (low incin future)	36	71	106	141	170	2,106		
Landfill (low incin future)	263	240	209	233	239	4,662		
Total waste accounted for (high)	323	384	452	537	589	9,151		
Total waste accounted for (low)	323	384	452	537	589	9,151		
Totals from PVC model	323	384	452	537	589	9,151		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (scenario1) - Electrical and electronic waste

Arisings

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	230	276	325	390	427	6,597
F	Adhesive tapes	39	43	49	56	62	996
F	Injection moulded parts	41	47	55	65	74	1,123
F	Various flexible products	10	14	18	19	19	329
R	Various rigid products	3	4	5	7	8	107

High Incineration future

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	74	86	114	136	1,770
F	Adhesive tapes	4	12	13	16	20	265
F	Injection moulded parts	5	12	15	19	24	301
F	Various flexible products	1	5	7	8	9	125
R	Various rigid products	0	1	2	3	4	41

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	186	147	135	151	154	3,019
F	Adhesive tapes	32	23	20	22	22	462
F	Injection moulded parts	33	25	23	25	27	516
F	Various flexible products	9	10	11	11	10	204
R	Various rigid products	2	3	3	4	4	66

Recycling

	E&E	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	18	55	104	125	137	1,807		1,807
F	Adhesive tapes	3	9	16	18	20	269		269
F	Injection moulded parts	3	9	18	21	24	307		307
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	50	75	100	121	1,490
F	Adhesive tapes	4	8	11	14	18	223
F	Injection moulded parts	5	9	13	17	21	253
F	Various flexible products	1	3	6	7	8	105
R	Various rigid products	0	1	2	2	3	35

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	186	170	147	165	169	3,299
F	Adhesive tapes	32	27	22	24	25	504
F	Injection moulded parts	33	29	25	28	29	563
F	Various flexible products	9	11	12	12	11	224
R	Various rigid products	2	3	4	4	4	72

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	25	73	137	164	180	2,383		**2383**
Incineration (high incin future)	36	104	123	160	192	2,502		
Landfill (high incin future)	263	207	192	213	218	4,266		
Incineration (low incin future)	36	71	106	141	170	2,106		
Landfill (low incin future)	263	240	209	233	239	4,662		
Total waste accounted for (high)	323	384	452	537	589	9,151		
Total waste accounted for (low)	323	384	452	537	589	9,151		
Totals from PVC model	323	384	452	537	589	9,151		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario2) - Electrical and electronic waste

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	64	63	84	100	1,369
F	Adhesive tapes	4	10	10	12	15	205
F	Injection moulded parts	4	11	11	14	17	233
F	Various flexible products	1	5	7	8	9	125
R	Various rigid products	0	1	2	3	4	41

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	182	129	99	111	113	2,435
F	Adhesive tapes	31	20	15	16	16	375
F	Injection moulded parts	33	22	17	19	20	417
F	Various flexible products	9	10	11	11	10	204
R	Various rigid products	2	3	3	4	4	66

High Incineration future

Arisings

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	230	276	325	390	427	6,597
F	Adhesive tapes	39	43	49	56	62	996
F	Injection moulded parts	41	47	55	65	74	1,123
F	Various flexible products	10	14	18	19	19	329
R	Various rigid products	3	4	5	7	8	107

Recycling

	E&E	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	23	83	163	195	213	2,793		2,793
F	Adhesive tapes	4	13	24	28	31	415		415
F	Injection moulded parts	4	14	27	33	37	473		473
F	Various flexible products								
R	Various rigid products								

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	44	55	73	89	1,147
F	Adhesive tapes	4	7	8	11	13	172
F	Injection moulded parts	4	7	9	12	15	195
F	Various flexible products	1	3	6	7	8	105
R	Various rigid products	0	1	2	2	3	35

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	182	149	108	121	125	2,657
F	Adhesive tapes	31	23	16	18	18	408
F	Injection moulded parts	33	25	18	20	22	455
F	Various flexible products	9	11	12	12	11	224
R	Various rigid products	2	3	4	4	4	72

Low Incineration future

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	31	110	215	256	281	3,681		**3681**
Incineration (high incin future)	35	92	92	121	144	1,973		
Landfill (high incin future)	257	183	145	161	164	3,497		
Incineration (low incin future)	35	63	80	106	128	1,653		
Landfill (low incin future)	257	212	157	176	180	3,816		
Total waste accounted for (high)	323	384	452	537	589	9,151		
Total waste accounted for (low)	323	384	452	537	589	9,151		
Totals from PVC model	323	384	452	537	589	9,151		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario3) - Electrical and electronic waste

Arisings

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	230	276	325	390	427	6,597
F	Adhesive tapes	39	43	49	56	62	996
F	Injection moulded parts	41	47	55	65	74	1,123
F	Various flexible products	10	14	18	19	19	329
R	Various rigid products	3	4	5	7	8	107

High Incineration future

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	74	86	114	136	1,770
F	Adhesive tapes	4	12	13	16	20	265
F	Injection moulded parts	5	12	15	19	24	301
F	Various flexible products	1	5	7	8	9	125
R	Various rigid products	0	1	2	3	4	41

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	186	147	135	151	154	3,019
F	Adhesive tapes	32	23	20	22	22	462
F	Injection moulded parts	33	25	23	25	27	516
F	Various flexible products	9	10	11	11	10	204
R	Various rigid products	2	3	3	4	4	66

Recycling

	E&E	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Cables	18	55	104	125	137	1,807		1,807
F	Adhesive tapes	3	9	16	18	20	269		269
F	Injection moulded parts	3	9	18	21	24	307		307
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	25	50	75	100	121	1,490
F	Adhesive tapes	4	8	11	14	18	223
F	Injection moulded parts	5	9	13	17	21	253
F	Various flexible products	1	3	6	7	8	105
R	Various rigid products	0	1	2	2	3	35

Landfill

	E&E	2000	2005	2010	2015	2020	Cum
F	Cables	186	170	147	165	169	3,299
F	Adhesive tapes	32	27	22	24	25	504
F	Injection moulded parts	33	29	25	28	29	563
F	Various flexible products	9	11	12	12	11	224
R	Various rigid products	2	3	4	4	4	72

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling	25	73	137	164	180	2,383		**2383**
Incineration (high incin future)	36	104	123	160	192	2,502		
Landfill (high incin future)	263	207	192	213	218	4,266		
Incineration (low incin future)	36	71	106	141	170	2,106		
Landfill (low incin future)	263	240	209	233	239	4,662		
Total waste accounted for (high)	323	384	452	537	589	9,151		
Total waste accounted for (low)	323	384	452	537	589	9,151		
Totals from PVC model	323	384	452	537	589	9,151		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (BAU) - Automotive waste

Arisings

	Auto	2000	2005	2010	2015	2020	Cum
F	Various flexible products	514	544	558	597	609	11,301
R	Various rigid products	14	18	23	29	36	478

High Incineration future

Incineration

	Auto	2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	189	230	279	315	4,514
R	Various rigid products	3	6	9	14	19	201

Landfill

	Auto	2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	355	327	318	295	6,787
R	Various rigid products	11	12	13	16	18	277

Recycling

	Auto	2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

	Auto	2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	146	201	248	283	3,920
R	Various rigid products	3	5	8	12	17	175

Landfill

	Auto	2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	397	356	349	326	7,381
R	Various rigid products	11	13	15	17	19	303

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	97	196	240	293	333	4,715		
Landfill (high incin future)	432	366	341	334	312	7,064		
Incineration (low incin future)	97	151	209	260	300	4,096		
Landfill (low incin future)	432	411	371	367	346	7,683		
Total waste accounted for (high)	528	562	580	627	645	11,779		
Total waste accounted for (low)	528	562	580	627	645	11,779		
Totals from PVC model	528	562	580	627	645	11,779		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario1) - Automotive waste

Arisings

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	514	544	558	597	609	11,301
R	Various rigid products	14	18	23	29	36	478

High Incineration future

Incineration

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	189	230	279	315	4,514
R	Various rigid products	3	6	9	14	19	201

Landfill

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	355	327	318	295	6,787
R	Various rigid products	11	12	13	16	18	277

Recycling

Auto		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	146	201	248	283	3,920
R	Various rigid products	3	5	8	12	17	175

Landfill

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	397	356	349	326	7,381
R	Various rigid products	11	13	15	17	19	303

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	97	196	240	293	333	4,715		
Landfill (high incin future)	432	366	341	334	312	7,064		
Incineration (low incin future)	97	151	209	260	300	4,096		
Landfill (low incin future)	432	411	371	367	346	7,683		
Total waste accounted for (high)	528	562	580	627	645	11,779		
Total waste accounted for (low)	528	562	580	627	645	11,779		
Totals from PVC model	528	562	580	627	645	11,779		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario2) - Automotive waste

Arisings

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	514	544	558	597	609	11,301
R	Various rigid products	14	18	23	29	36	478

High Incineration future

Incineration

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	189	230	279	315	4,514
R	Various rigid products	3	6	9	14	19	201

Landfill

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	355	327	318	295	6,787
R	Various rigid products	11	12	13	16	18	277

Recycling

Auto		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	146	201	248	283	3,920
R	Various rigid products	3	5	8	12	17	175

Landfill

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	397	356	349	326	7,381
R	Various rigid products	11	13	15	17	19	303

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	97	196	240	293	333	4,715		
Landfill (high incin future)	432	366	341	334	312	7,064		
Incineration (low incin future)	97	151	209	260	300	4,096		
Landfill (low incin future)	432	411	371	367	346	7,683		
Total waste accounted for (high)	528	562	580	627	645	11,779		
Total waste accounted for (low)	528	562	580	627	645	11,779		
Totals from PVC model	528	562	580	627	645	11,779		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario3) - Automotive waste

Arisings

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	514	544	558	597	609	11,301
R	Various rigid products	14	18	23	29	36	478

High Incineration future

Incineration

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	189	230	279	315	4,514
R	Various rigid products	3	6	9	14	19	201

Landfill

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	355	327	318	295	6,787
R	Various rigid products	11	12	13	16	18	277

Recycling

Auto		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	94	146	201	248	283	3,920
R	Various rigid products	3	5	8	12	17	175

Landfill

Auto		2000	2005	2010	2015	2020	Cum
F	Various flexible products	420	397	356	349	326	7,381
R	Various rigid products	11	13	15	17	19	303

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	97	196	240	293	333	4,715		
Landfill (high incin future)	432	366	341	334	312	7,064		
Incineration (low incin future)	97	151	209	260	300	4,096		
Landfill (low incin future)	432	411	371	367	346	7,683		
Total waste accounted for (high)	528	562	580	627	645	11,779		
Total waste accounted for (low)	528	562	580	627	645	11,779		
Totals from PVC model	528	562	580	627	645	11,779		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (BAU) - 'Other' waste

Arisings

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	60	60	60	62	62	1,211
R	Various rigid products						

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

High Incineration future

Recycling

Other		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Low Incineration future

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	30	30	30	31	31	605		
Landfill (high incin future)	30	30	30	31	31	605		
Incineration (low incin future)	30	30	30	31	31	605		
Landfill (low incin future)	30	30	30	31	31	605		
Total waste accounted for (high)	60	60	60	62	62	1,211		
Total waste accounted for (low)	60	60	60	62	62	1,211		
Totals from PVC model	60	60	60	62	62	1,211		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (BAU) - 'Other' waste

Arisings

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	60	60	60	62	62	1,211
R	Various rigid products						

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

High Incineration future

Recycling

Other		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Low Incineration future

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	30	30	30	31	31	605		
Landfill (high incin future)	30	30	30	31	31	605		
Incineration (low incin future)	30	30	30	31	31	605		
Landfill (low incin future)	30	30	30	31	31	605		
Total waste accounted for (high)	60	60	60	62	62	1,211		
Total waste accounted for (low)	60	60	60	62	62	1,211		
Totals from PVC model	60	60	60	62	62	1,211		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario2) - 'Other' waste

Arisings

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	60	60	60	62	62	1,211
R	Various rigid products						

High Incineration future

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Recycling

Other		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

Low Incineration future

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	30	30	30	31	31	605		
Landfill (high incin future)	30	30	30	31	31	605		
Incineration (low incin future)	30	30	30	31	31	605		
Landfill (low incin future)	30	30	30	31	31	605		
Total waste accounted for (high)	60	60	60	62	62	1,211		
Total waste accounted for (low)	60	60	60	62	62	1,211		
Totals from PVC model	60	60	60	62	62	1,211		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Waste destinations (Scenario3) - 'Other' waste

Arisings

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	60	60	60	62	62	1,211
R	Various rigid products						

High Incineration future

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Low Incineration future

Incineration

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Landfill

Other		2000	2005	2010	2015	2020	Cum
F	Various flexible products	30	30	30	31	31	605
R	Various rigid products						

Recycling

Other		2000	2005	2010	2015	2020	Cum	HQR	LQR
F	Various flexible products								
R	Various rigid products								

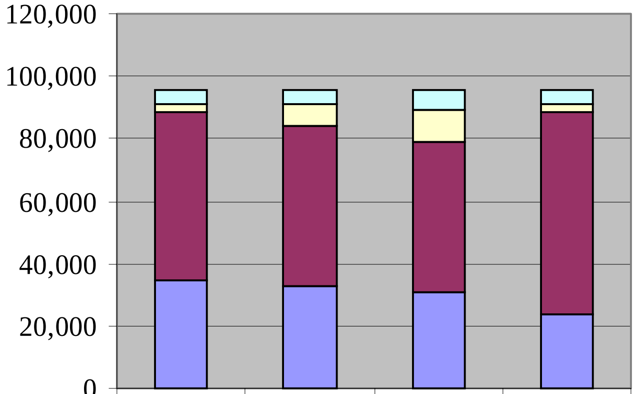
TOTALS (check)	2000	2005	2010	2015	2020	Cum	HQR	LQR
Recycling								
Incineration (high incin future)	30	30	30	31	31	605		
Landfill (high incin future)	30	30	30	31	31	605		
Incineration (low incin future)	30	30	30	31	31	605		
Landfill (low incin future)	30	30	30	31	31	605		
Total waste accounted for (high)	60	60	60	62	62	1,211		
Total waste accounted for (low)	60	60	60	62	62	1,211		
Totals from PVC model	60	60	60	62	62	1,211		

Key: Cum=cumulative PVC waste 2000 to2020, HQR=high quality recycling
LQR=low quality recycling

Appendix 2.
Cumulative PVC waste destinations 2000 - 2020

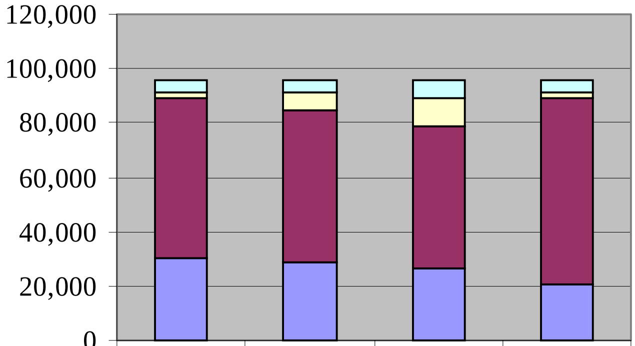
Figure 1: Cumulative PVC waste destinations (ktonnes) in EU-21, 2000-2020

EU-21, high incineration



	BAU	Scenario 1	Scenario 2	Scenario 3
Recycling, low qual	4,476	4,476	6,363	4,476
Recycling, high qual	2,349	6,856	10,229	2,349
Landfill	54,017	51,342	48,323	65,081
Incineration	34,789	32,957	30,715	23,725

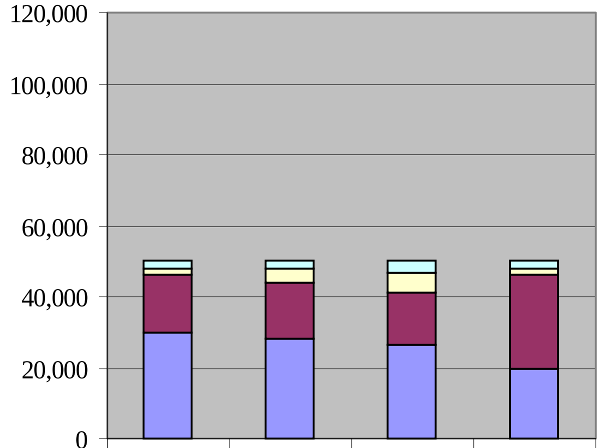
EU-21, low incineration



	1	2	3	4
Recycling, low qual	4,476	4,476	6,363	4,476
Recycling, high qual	2,349	6,856	10,229	2,349
Landfill	58,519	55,609	52,299	68,090
Incineration	30,287	28,691	26,740	20,716

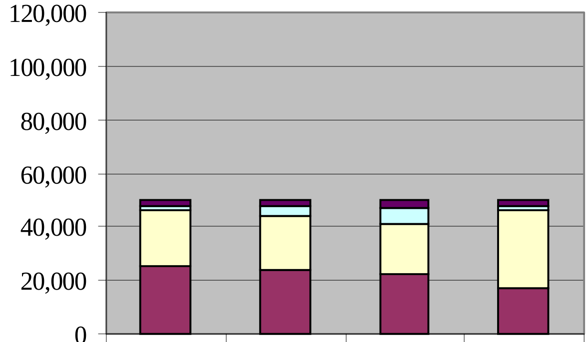
Figure 2: Cumulative PVC waste destinations (ktonnes) in Landfill Directive Plus countries, 2000-2020

Landfill Directive Plus, high incineration



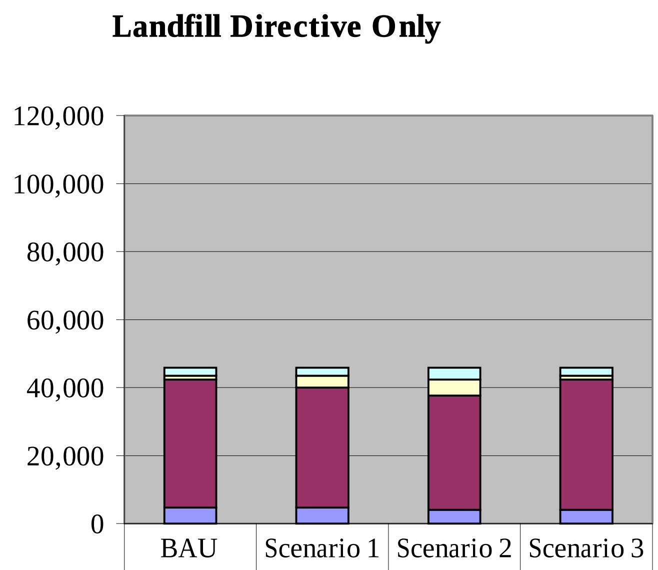
	BAU	Scenario 1	Scenario 2	Scenario 3
Recycling, low qual	2,335	2,335	3,319	2,335
Recycling, high qual	1,225	3,573	5,331	1,225
Landfill	16,436	15,761	14,979	26,529
Incineration	29,973	28,300	26,339	19,880

Landfill Directive Plus, low incineration



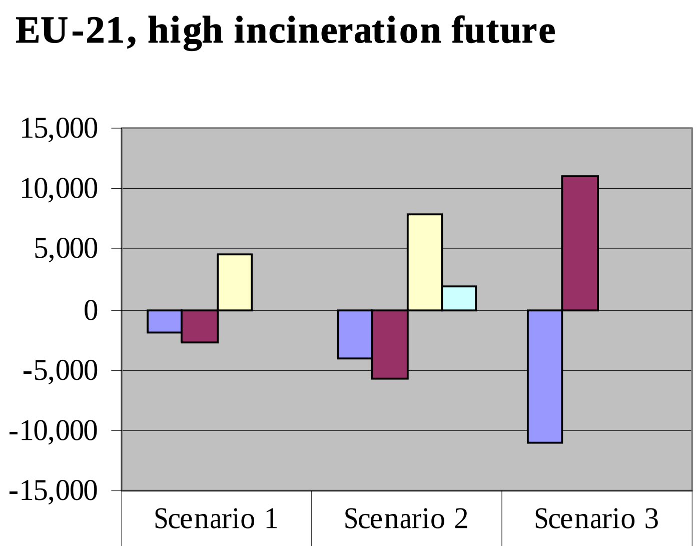
	1	2	3	4
Recycling, low qual	2,335	2,335	3,319	2,335
Recycling, high qual	1,225	3,573	5,331	1,225
Landfill	20,937	20,028	18,955	29,538
Incineration	25,472	24,033	22,364	16,871

Figure 3: Cumulative PVC waste destinations (ktonnes) in Landfill Directive Only countries, 2000-2020

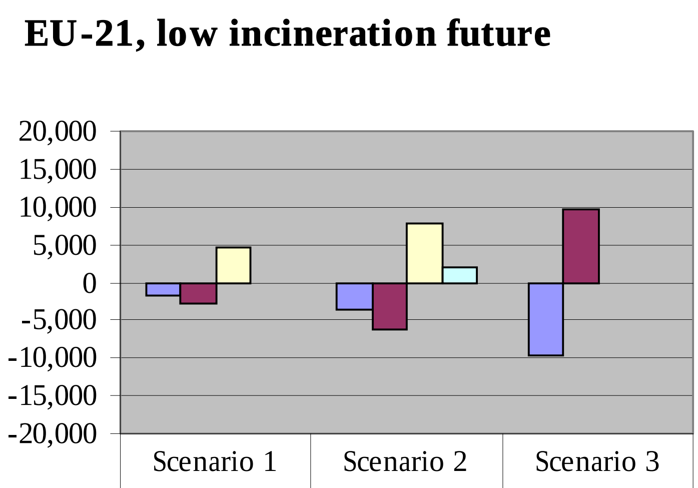


	BAU	Scenario 1	Scenario 2	Scenario 3
Recycling, low qual	2,141	2,141	3,044	2,141
Recycling, high qual	1,124	3,283	4,898	1,124
Landfill	37,581	35,581	33,344	38,552
Incineration	4,816	4,658	4,376	3,845

Figure 4: Change in cumulative PVC waste destinations (2000-2020), relative to BAU (ktonnes)

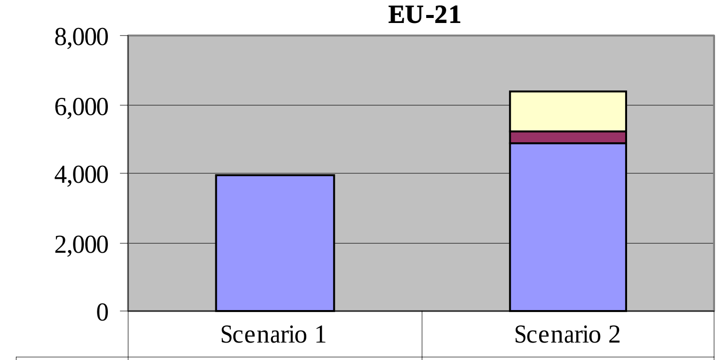


	Scenario 1	Scenario 2	Scenario 3
Incineration	-1,832	-4,073	-11,064
Landfill	-2,675	-5,694	11,064
Recycling, high qual	4,507	7,880	0
Recycling, low qual	0	1,887	0



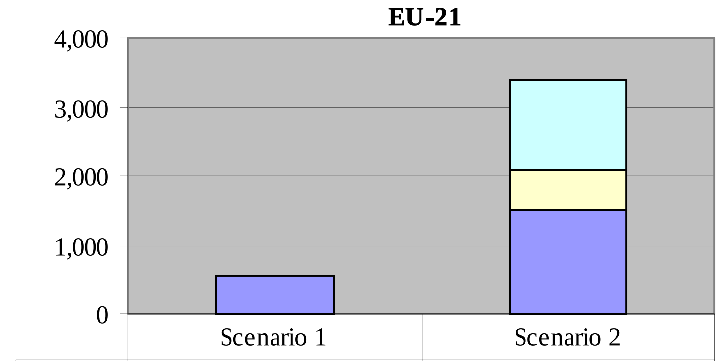
	Scenario 1	Scenario 2	Scenario 3
Incineration	-1,597	-3,548	-9,571
Landfill	-2,910	-6,220	9,571
Recycling, high qual	4,507	7,880	0
Recycling, low	0	1,887	0

Figure 5: Change in cumulative PVC product groups to recycling (2000-2020) relative to BAU - Rigid PVC



	Scenario 1	Scenario 2
E&E	0	0
H&C	0	1,183
Packag	0	343
Constr	3,948	4,851

Figure 6: Change in cumulative PVC product groups to recycling (2000-2020) relative to BAU - Flexible PVC



	Scenario 1	Scenario 2
E&E	0	1,298
H&C	0	580
Packag	0	0
Constr	558	1,512

Appendix 3.
Control of acid gas emissions

The information provided in this chapter has been summarised from the Bertin study on PVC incineration[1], which provides an extensive review of acid gas abatement, to which the reader is referred for further details.

Figure 7: Characteristics of acid gas pollution control systems.

Dry systems

- Solid powdered neutralising agent is sprayed into the combustion gas flow after it leaves the heat recovery boiler.
- Fly ash, neutralising reagent and neutralising reagent excess are recovered from the effluent gas by fabric filters and/or electrostatic precipitators.
- Calcium hydroxide ($Ca(OH)_2$) and sodium bicarbonate ($NaHCO_3$) are commonly used reagents, the latter mostly for smaller scale incinerators at present. Dry systems using calcium carbonate or calcium oxide are seldom used today, because of the inefficiency of the former and the handling difficulties of the latter.

Semi-dry systems

- Includes systems where powdered neutralising agent is fed into the gas stream down stream from a water spray (semi-dry), and systems where the neutralising agent is injected as a solution or suspension in water (semi-wet).
- In the semi-wet system, the water evaporates to leave a solid residue of neutralisation products and excess reagent that is then captured with fabric filters and electrostatic precipitators.

Wet systems

- Wet systems usually comprise of an electrostatic precipitator downstream of the boiler to remove fly ash followed by an acid and then neutral scrubber.
- The acid gas scrubber operates at 50-70 °C and so some of the water vapour in the combustion gas condenses here. Over 95 per cent of the hydrogen chloride is absorbed in the acid scrubber. The pH is kept at about 3 by additions of limewater or sodium hydroxide, to prevent saturation with hydrogen chloride. In some five German incinerators (and another three under construction), the acid scrubber is operated with water alone to allow the recovery of concentrated (33 per cent) hydrochloric acid for subsequent purification and sale.
- The neutral scrubber is kept at about pH7 through additions of lime water or sodium hydroxide solution. Sulphur dioxide and most of the remaining hydrogen chloride is absorbed at this stage.
- The liquid effluent from the scrubber is adjusted to pH9 to 11 with lime to precipitate heavy metals and gypsum (calcium sulphate). The solids are separated for stabilisation and landfill disposal. The liquor is then discharged, where suitable consents have been obtained.

Semi wet-wet system

- Consents for liquid effluent discharge are becoming increasingly hard to obtain in some countries. As a result, a variation on the wet systems is being increasingly adopted. In this system (semi wet-wet) the effluent from the acid and neutral scrubbers are treated with alkali (lime and or sodium hydroxide) to precipitate gypsum and heavy metals, before being fed back into a spray drier up stream of the electrostatic precipitator. The drier produces a solid residue of salts that are then collected with the fly ash in the electrostatic precipitators.

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[1] Bertin Technologies (1999). Final project report to DGXI contract number B463040/98/000101/MAR/E3. The influence of PVC on the quantity and hazardousness of flue gas residues from incineration.

CALCULATION OF REAGENTS AND RESIDUES INVOLVED WITH ACID GAS ABATEMENT

Dry systems using sodium bicarbonate ($NaHCO_3$) absorption:

Solid sodium bicarbonate (sodium hydrogen carbonate) is freshly crushed just before being injected into the combustion gas stream, resulting in a high porosity and specific area for the solid, which leads to efficient absorption of acid gases and low stoichiometric ratio (SR). The process can achieve the 10 mg/Nm^3 HCl and 50 mg/Nm^3 SO_2 emission limits in the proposed Incineration Directive.

Hydrogen chloride absorption:
The relevant chemical equation for neutralisation is:

$$HCl + SR\ NaHCO_3 \rightarrow NaCl + H_2O + CO_2 + (SR-1)\ NaHCO_3$$

The excess bicarbonate decomposes into carbon dioxide and sodium carbonate, so reducing the quantity of excess reagent needing disposal:

$$(SR-1)\ NaHCO_3 \rightarrow ½\ (SR-1)\ Na_2CO_3 + ½(SR-1)H_2O + ½(SR-1)CO_2$$

For dry systems using $NaHCO_3$ for HCl absorption, SR=1.05 (all SR values used here are taken from the Bertin study[1]). Therefore, on combining the above equations, we get:

$$HCl + 1.05NaHCO_3 \rightarrow NaCl + 1.025\ H_2O + 1.025\ CO_2 + 0.025Na_2CO_3$$

Equivalent masses[2] (excluding product gases):

36.5	1.05 x 84	58.5	0.025 x 106
36.5	88.2	58.5	2.65

So 36.5 kg of hydrogen chloride (containing 35.5 kg of chlorine) requires 88.2 kg of sodium bicarbonate with SR 1.05, producing 58.5 kg of sodium chloride and 2.65 kg of sodium carbonate for disposal. Therefore for every kg of chlorine entering the APC system, 2.48 kg of sodium bicarbonate is needed, producing 1.65 kg of sodium chloride and 0.075 kg of sodium carbonate co-product.

Sulphur dioxide absorption:
In this case, the neutralisation process is governed by the following equations:

$$SO_2 + 2SR\ NaHCO_3 + ½O_2 \rightarrow Na_2SO_4 + 2CO_2 + H_2O + 2(SR-1)\ NaHCO_3$$

and

$$2(SR-1)\ NaHCO_3 \rightarrow (SR-1)\ Na_2CO_3 + (SR-1)H_2O + (SR-1)CO_2$$

For SR=1.2, therefore:

---

[2] The equivalent masses are based on the following atomic masses: H=1, Cl=35.5, O=16, Ca=40, S=32, Na=23.

SO_2 + 2.4 $NaHCO_3$ + ½O_2 → Na_2SO_4 + 2.2CO_2 + 1.2H_2O + 0.2 Na_2CO_3

Equivalent masses:

64	2.2 x 84	142	0.2 x 106
64	201.6	142	21.2

So 64 kg of sulphur dioxide (containing 32 kg of sulphur) require 201.6 kg of calcium hydroxide and produce 142 kg of sodium sulphate and 21.2 kg of sodium carbonate. Therefore every kg of sulphur entering the APC system requires 6.3 kg of sodium bicarbonate and produces 4.44 kg of sodium sulphate and 0.66 kg of sodium carbonate co-product.

Summary results for dry systems using sodium bicarbonate: Units are kg reagent or residue / kg of chlorine or sulphur entering the APC system.

Reagent / product	Compound	Factor	Compound	Factor
	Chlorine SR=1.05		Sulphur SR=1.2	
Reagent demand	$NaHCO_3$	2.48	$NaHCO_3$	6.3
Reaction product	NaCl	1.65	Na_2SO_4	4.44
Excess reagent / co-product	Na_2CO_3	0.075	Na_2CO_3	0.66

Dry systems using calcium hydroxide (lime):

Dry systems using calcium hydroxide as absorbent require a considerable excess of reagent (i.e. high SR) to operate satisfactorily and are unlikely to achieve the proposed Incineration limits for HCl and SO_2 whatever the excess lime addition. Several MSW incinerators have therefore replaced dry lime injection with semi-dry systems.

Hydrogen chloride absorption[3]:

$$2HCl + SR\ Ca(OH)_2 \rightarrow CaCl_2.2H_2O + (SR-1)\ Ca(OH)_2$$

For dry systems, SR=2.0, therefore:

$$2HCl + 2.0\ Ca(OH)_2 \rightarrow CaCl_2.2H_2O + Ca(OH)_2$$

Equivalent masses:

73	2 x 74	147	74
73	148	147	74

So 73 kg of hydrogen chloride (containing 71 kg of chlorine) requires 148 kg of calcium hydroxide at SR 2.0 for abatement, producing 147 kg of calcium chloride dihydrate for disposal, along with 74 kg of unreacted calcium hydroxide. Therefore for every kg of chlorine entering the APC system, 2.08 kg of calcium hydroxide is needed, producing 2.07 kg of calcium chloride and 1.04 kg of unreacted reagent.

[3] The Bertin study reported that the product of the reaction of HCl with lime when the latter is in excess is actually calcium hydroxichloride, CaOHCl . However, in line with common practise, they adopt the simplified global reaction $Ca(OH)_2$ + 2HCl → $CaCl_2$ $2H_2O$, pointing out that this does not affect the quantity of solid residues recovered after neutralisation.

Sulphur dioxide absorption:

$$SO_2 + SR\ Ca(OH)_2 + O_2 \rightarrow CaSO_4.2H_2O + (SR-1)\ Ca(OH)_2$$

For dry systems, SR=4.0, therefore:

$$SO_2 + 4.0\ Ca(OH)_2 + ½O_2 + H_2O \rightarrow CaSO_4.2H_2O + 3.0\ Ca(OH)_2$$

Equivalent masses (neglecting O_2):

64	4 x 74	172	3 x 74
64	296	172	222

So 64 kg of sulphur dioxide (containing 32 kg of sulphur) require 298 kg of calcium hydroxide and produce 172 kg of calcium sulphate dihydrate and 222 kg of unreacted calcium hydroxide. Therefore every kg of sulphur entering the APC system requires 9.25 kg of calcium hydroxide and produces 5.38 kg of calcium sulphate and leaves 6.94 kg of unreacted reagent.

Summary results for dry systems using lime: Units are kg / kg of element entering the APC system.

Reagent / product	Compound	Factor	Compound	Factor
	Chlorine SR=2.0		Sulphur SR=4.0	
Reagent demand	$Ca(OH)_2$	2.08	$Ca(OH)_2$	9.25
Reaction product	$CaCl_2\ 2H_2O$	2.07	$CaSO_4\ 2H_2O$	5.38
Excess reagent / co-product	$Ca(OH)_2$	1.04	$Ca(OH)_2$	6.94

Semi dry systems:

Semi-dry systems using lime as absorbent can achieve the emission limits for HCl and SO_2 given in the proposed Incineration Directive.

Hydrogen chloride absorption:

$$2HCl + SR\ Ca(OH)_2 \rightarrow CaCl_2.2H_2O + (SR-1)\ Ca(OH)_2$$

For semi-dry systems, SR=1.7, therefore:

$$2HCl + 1.7\ Ca(OH)_2 \rightarrow CaCl_2.2H_2O + 0.7\ Ca(OH)_2$$

Equivalent masses:

73	1.7 x 74	147	0.7 x 74
73	125.8	147	51.8

So 73 kg of hydrogen chloride (containing 71 kg of chlorine) requires 125.8 kg of calcium hydroxide at SR 1.7 for abatement, producing 147 kg of calcium chloride dihydrate for disposal, along with 51.8 kg of unreacted calcium hydroxide. Therefore for every kg of chlorine entering the APC system, 1.77 kg of calcium hydroxide is needed, producing 2.07 kg of calcium chloride and 0.73 kg of unreacted reagent.

Sulphur dioxide absorption:

SO_2 + SR $Ca(OH)_2$ + ½O_2 + H_2O → $CaSO_4.2H_2O$ + (SR-1) $_{Ca(OH)2}$

For semi-dry systems, SR=4.0, therefore:

SO_2 + 4 $Ca(OH)_2$ + ½O_2 + H_2O → $CaSO_4.2H_2O$ + 3 $Ca(OH)_2$

Results in this case are the same as for dry lime systems, given above.

Summary results for semi-dry systems using lime: Units are kg / kg of element entering the APC system.

Reagent / product	Compound	Factor	Compound	Factor
	Chlorine SR=1.7		Sulphur SR=4.0	
Reagent demand	$Ca(OH)_2$	1.77	$Ca(OH)_2$	9.25
Reaction product	$CaCl_2$ $2H_2O$	2.07	$CaSO_4$ $2H_2O$	5.38
Excess reagent / co-product	$Ca(OH)_2$	0.73	$Ca(OH)_2$	6.94

Wet systems

In wet absorption systems, HCl neutralisation is achieved with a stoichiometric quantity of sodium hydroxide (SR=1.0) and an excess of lime, which is also required by sulphur dioxide absorption, as follows:

HCl + 0.5 NaOH + 0.25 SR $Ca(OH)_2$ → 0.5 NaCl+0.25 $CaCl_2$+0.25(SR-1) $Ca(OH)_2$ +H_2O

SR =1.1 for $Ca(OH)_2$, therefore:

HCl + 0.5 NaOH + 0.275$Ca(OH)_2$ → 0.5NaCl + 0.25$CaCl_2$ + 0.025$Ca(OH)_2$ + H_2O

Equivalent masses of relevant reactants and products:

36.5	0.5 x 40	0.275 x 74	0.5 x 58.5	0.25 x 111	0.025 x 74
36.5	20	20.35	29.25	27.75	1.85

So 36.5 kg of hydrogen chloride (containing 35.5 kg of chlorine) requires 20 kg of sodium hydroxide and 20.35 kg of lime for neutralisation, producing 29.25 kg of sodium chloride and 27.75 kg of calcium chloride, and leaving an excess of 1.85 kg of lime. Therefore every kg of chlorine entering the APC system needs 0.563 kg of sodium hydroxide and 0.573 kg of calcium hydroxide, to produce a liquid effluent containing 0.824 kg of sodium chloride and 0.782 kg of calcium chloride and 0.0521 kg of excess lime.

For sulphur dioxide absorption, the relevant reaction is:

SO_2 + SR $Ca(OH)_2$ + ½ O_2 → ↓$CaSO_4$ + H_2O + (1-SR) $Ca(OH)_2$

Taking SR=1.1, the overall equation becomes:

SO_2 + 1.1$Ca(OH)_2$ + ½ O_2 → ↓$CaSO_4$ + H_2O + 0.1 $Ca(OH)_2$

Equivalent masses:

64	1.1 x 74	136	0.1 x 74
64	81.4	136	7.4

So 64 kg of sulphur dioxide (containing 32 kg of sulphur) requires 81.4 kg of lime and produces 136 kg of calcium sulphate (gypsum) sludge and leaves 7.4 kg of excess lime. Therefore every kg of sulphur requires 2.544 kg of lime and produces 4.25 kg of gypsum sludge (recovered as filter cake for disposal) and 0.231 kg of excess lime in solution.

Summary results for wet systems: Units are kg / kg of element entering the APC system.

Reagent / product	Compound	Factor	Compound	Factor
	Chlorine SR=1.1 (lime) SR=1.0 (NaOH)		Sulphur SR=1.1 (lime) SR=1.0 (NaOH)	
Reagent demand	$Ca(OH)_2$	0.573	$Ca(OH)_2$	2.544
Reagent demand	NaOH	0.563		
Salts in liquid effluent				
Reaction product	$CaCl_2$	0.782		
Reaction product	NaCl	0.824		
Excess reagent / co-product	$Ca(OH)_2$	0.0521	$Ca(OH)_2$	0.231
Filter cake solid residue				
			$CaSO_4$	4.25

Semi-wet wet systems

In the semi-wet wet process, the liquid effluent is eliminated by evaporation to produce a salt residue for disposal. The absorption reactions are the same as described for the wet process, except that we need to consider the hydration state in which the salts are recovered. In this case, the products are recovered as $CaCl_2\ 2H_2O$ and $CaSO_4\ 2H_2O$. The appropriate correction has been applied to the data shown in the summary table given below.

Summary results for semi-wet wet systems: Units are kg / kg of element entering the APC system.

Reagent / product	Compound	Factor	Compound	Factor
	Chlorine SR=1.1 (lime) SR=1.0 (NaOH)		Sulphur SR=1.1 (lime) SR=1.0 (NaOH)	
Reagent demand	$Ca(OH)_2$	0.573	$Ca(OH)_2$	2.544
Reagent demand	NaOH	0.563		
Solid residues				
Reaction product	$CaCl_2\ 2H_2O$	1.035	$CaSO_4\ 2H_2O$	5.375
Reaction product	NaCl	0.824		
Excess reagent / co-product	$Ca(OH)_2$	0.0521	$Ca(OH)_2$	0.231

Semi-wet wet absorption with hydrogen chloride recovery

Five German incinerators currently recover hydrogen chloride as concentrated hydrochloric acid (33 per cent of HCl by weight in water) for sale. No lime or sodium hydroxide is required for neutralisation and no chloride residue is produced. Neutralising agents are still required for sulphur dioxide absorption, but overall the quantity of reagent and residues / effluent are greatly reduced. The absorption of hydrogen chloride follows the reactions:

$HCl_{(gas)} + H_2O \rightarrow HCl_{(solution)} + H_2O$
$HCl_{(solution)} + H_2O \rightarrow H_3O^+ + Cl^-$

From the ratio of the molecular masses, 1.03 kg of hydrogen chloride in solution is recovered from every kg of chlorine absorbed.

Summary results for semi-wet wet systems recovering hydrochloric acid: Units are kg / kg of element entering the APC system.

Reagent / product	Compound	Factor	Compound	Factor
	Chlorine SR=0 (lime) SR=0 (NaOH)		Sulphur SR=1.1 (lime) SR=1.0 (NaOH)	
Reagent demand	$Ca(OH)_2$	0	$Ca(OH)_2$	2.544
Reagent demand	NaOH	0		
Solid residues				
Reaction product	$CaCl_2\ 2H_2O$	0	$CaSO_4\ 2H_2O$	5.375
Reaction product	NaCl	0		
Excess reagent / co-product	$Ca(OH)_2$	0	$Ca(OH)_2$	0.231
Recovered product	HCl (in aqueous solution)	1.03		

Overall results

The overall quantities of reagent and residues for each of the APC systems described above are summarised in Table 1.

Table 1: Summary table of reaction factors for HCl and SO_2 abatement by various APC systems.

Factors are the amounts of reagent and residue per kg of Cl or S entering the APC system.

	Chlorine		Sulphur	
	Compound	**Factor**	**Compound**	**Factor**
Dry $NaHCO_3$ -based systems				
Reagent demand				
	$NaHCO_3$	2.48	$NaHCO_3$	6.3
Solid residues				
Reaction product	NaCl	1.65	Na_2SO_4	4.44
Excess reagent / co-product	Na_2CO_3	0.075	Na_2CO_3	0.66
Dry lime-based systems				
Reagent demand				
	$Ca(OH)_2$	2.08	$Ca(OH)_2$	9.25
Solid residues				
Reaction product	$CaCl_2$ $2H_2O$	2.07	$CaSO_4$ $2H_2O$	5.38
Excess reagent / co-product	$Ca(OH)_2$	1.04	$Ca(OH)_2$	6.94
Semi dry lime-based systems				
Reagent demand				
	$Ca(OH)_2$	1.77	$Ca(OH)_2$	9.25
Solid residues				
Reaction product	$CaCl_2$ $2H_2O$	2.07	$CaSO_4$ $2H_2O$	5.38
Excess reagent / co-product	$Ca(OH)_2$	0.73	$Ca(OH)_2$	6.94
Wet systems				
Reagent demand				
	$Ca(OH)_2$	0.573	$Ca(OH)_2$	2.544
	NaOH	0.563		
Salts in liquid effluent				
Reaction product	$CaCl_2$	0.782		
Reaction product	NaCl	0.824		
Excess reagent / co-product	$Ca(OH)_2$	0.0521	Ca(OH)2	0.231
Solid residues				
Reaction product (filter cake)			CaSO4	4.25
Semi-wet wet systems				
Reagent demand				
	$Ca(OH)_2$	0.573	$Ca(OH)_2$	2.544
	NaOH	0.563		
Solid residue				
Reaction product	$CaCl_2$ $2H_2O$	1.035	$CaSO_4$ $2H_2O$	5.375
Reaction product	NaCl	0.824		
Excess reagent / co-product	$Ca(OH)_2$	0.0521	$Ca(OH)_2$	0.231
Semi-wet wet with HCl recovery				
Reagent demand				
			$Ca(OH)_2$	2.544
Solid residue				
Reaction product			$CaSO_4$ $2H_2O$	5.375
Excess reagent / co-product			$Ca(OH)_2$	0.231
Recovered product				
	HCl in solution	1.03		

OVERALL REAGENT CONSUMPTION AND RESIDUE PRODUCTION

The reaction factors shown above have been used to estimate the reagent requirement and residue production from the combustion of PVC with MSW. We assume that PVC contributes half of the chlorine present in MSW. All of the chlorine coming from PVC is assumed to require neutralisation, whilst for MSW (where the non-PVC chlorine is mostly present as alkali and alkaline earth metal chlorides of high thermal stability), only 70 per cent is estimated to enter the APC system, the remainder being neutralised by grate and fly ash. In the case of sulphur, some 50 per is assumed to be neutralised by these residues.

From PVC-free MSW

Element	Concentration in waste, kg/tonne	Per cent needing neutralisation	Concentration for neutralisation, kg/tonne of waste
Cl from PVC	0	100%	0
Cl from MSW	3.19	70%	2.233
S in MSW	1.2	50%	0.6
Cl for neutr	3.19	70%	2.23
S for neutr	1.20	50%	0.60

		Dry lime	Dry bicarb	Semi dry lime	Wet	Semi-wet wet	APC average
	System deployment	**0%**	**0%**	**25%**	**25%**	**50%**	
REAGENTS							
For Cl							
	Lime	4.64	0.00	3.95	1.28	1.28	1.95
	Bicarb	0.00	5.54	0.00	0.00	0.00	0.00
	NaOH	0.00	0.00	0.00	1.26	1.26	0.94
	Total	**4.64**	**5.54**	**3.95**	**2.54**	**2.54**	**2.89**
For S							
	Lime	5.55	0	5.55	1.524	1.524	2.53
	Bicarb	0	3.78	0	0	0	0.00
	NaOH	0	0	0	0	0	0.00
	Total for S	5.55	3.78	5.55	1.524	1.524	2.53
	Total for Cl and S	**10.19**	**9.32**	**9.50**	**4.06**	**4.06**	**5.42**
RESIDUES							
APC residues							
For Cl							
	Ca(OH)Cl.H20	6.92	0.00	0.00	0.00	0.00	0.00
	CaCl2..2H2O	0.00	0.00	4.62	0.00	2.31	2.31
	Ca(OH)2	0.00	0.00	1.63	0.00	0.12	0.47
	NaCl	0.00	3.68	0.00	0.00	1.84	0.92
	Na2CO3	0.00	0.17	0.00	0.00	0.00	0.00
	Total	**6.92**	**3.85**	**6.25**	**0.00**	**4.27**	**3.70**
For S							
	CaSO4.2H2O	3.222	0	3.225	0	3.225	2.42
	Ca(OH)2	4.158	0	4.158	2.58	0.138	1.75
	Na2SO4	0	2.64	0	0	0	0.00
	Na2CO3	0	0.396	0	0	0	0.00
	Total	**7.38**	**3.036**	**7.383**	**2.58**	**3.363**	**4.17**
Total							
	For Cl and S	**14.3**	**6.9**	**13.6**	**2.6**	**7.63**	**7.87**

From MSW where PVC contributes 50% of the chlorine

Element	Concentration in waste, kg/tonne	Per cent needing neutralisation	Concentration for neutralisation, kg/tonne of waste
Cl from PVC	3.19	100%	3.19
Cl from MSW	3.19	70%	2.233
S in MSW	1.2	50%	0.6
Cl for neutr	6.38	70%	5.42
S for neutr	1.20	50%	0.60

		Dry lime	Dry bicarb	Semi dry lime	Wet	Semi-wet wet	APC average
	System deployment	**0%**	**0%**	**25%**	**25%**	**50%**	
REAGENTS							
For Cl							
	Lime	11.28	0.00	9.60	3.11	3.11	4.73
	Bicarb	0.00	13.45	0.00	0.00	0.00	0.00
	NaOH	0.00	0.00	0.00	3.05	3.05	2.29
	Total	**11.28**	**13.45**	**9.60**	**6.16**	**6.16**	**7.02**
For S							
	Lime	5.55	0	5.55	1.524	1.524	2.53
	Bicarb	0	3.78	0	0	0	0.00
	NaOH	0	0	0	0	0	0.00
	Total for S	5.55	3.78	5.55	1.524	1.524	2.53
	Total for Cl and S	**16.83**	**17.23**	**15.15**	**7.68**	**7.68**	**9.55**
RESIDUES							
APC residues							
For Cl							
	Ca(OH)Cl.H20	16.81	0.00	0.00	0.00	0.00	0.00
	CaCl2..2H2O	0.00	0.00	11.23	0.00	5.61	5.61
	Ca(OH)2	0.00	0.00	3.96	0.00	0.28	1.13
	NaCl	0.00	8.95	0.00	0.00	4.47	2.23
	Na2CO3	0.00	0.41	0.00	0.00	0.00	0.00
	Total	**16.81**	**9.35**	**15.18**	**0.00**	**10.36**	**8.98**
For S							
	CaSO4.2H2O	3.222	0	3.225	0	3.225	2.42
	Ca(OH)2	4.158	0	4.158	2.58	0.138	1.75
	Na2SO4	0	2.64	0	0	0	0.00
	Na2CO3	0	0.396	0	0	0	0.00
	Total	**7.38**	**3.036**	**7.383**	**2.58**	**3.363**	**4.17**
Total							
	For Cl and S	**24.2**	**12.4**	**22.6**	**2.6**	**13.73**	**13.15**

Additional reagents and residues attributable to PVC (average APC systems).

Reagent use.

Reagents required for MSW = 5.42 kg / tonne of MSW

Reagent required for MSW with PVC providing 3.19 kg Cl /tonne = 9.55 kg / tonne of MSW.

Therefore reagent use attributable to PVC = 9.55 – 5.42 = 4.13 kg/tonne of MSW.

Amount of PVC needed to provide 3.19 kg Cl/tonne of MSW:

Rigid PVC = 5.89 kg rigid PVC is equivalent to 3.19 kg of Cl (since 1 kg of rigid PVC contains 0.541 kg of Cl). **Therefore increased reagent demand if all PVC is rigid would be 700 kg / tonne of PVC** (ie 4.13 / (5.89/1000)).

Flexible PVC = 9.44 kg flexible PVC is equivalent to 3.19 kg of Cl (since 1 kg of flexible PVC contains 0.338 kg of Cl). **Therefore increased reagent demand attributable to flexible PVC would be 438 kg / tonne of PVC** (ie 4.13 / (9.44/1000)).

APC Residues

Residues from MSW only = 7.87 kg/tonne of MSW

Residues from MSW with PVC = 13.15 kg/tonne of MSW

Residues attributable to PVC = 5.28 kg/tonne of MSW.

Additional residues attributable to rigid PVC = 896 kg / tonne of PVC (ie 5.28/(5.89/1000)).

Additional residues attributable to flexible PVC = 559 kg / tonne of PVC (ie 5.28/(9.44/1000)).

Appendix 4.
Burdens from NaOH and PVC manufacture

Gross inputs and outputs from production of 1kg NaOH

Boustead, I (1994) Ecoprofiles of the European Polymer Industry Report 6: Polyvinyl chloride. APME Technical Centre, Brussels

Air emissions	Dust	mg	3100
	Carbon monoxide	mg	700
	Carbon dioxide	mg	1120000
	Sulphur oxides	mg	10000
	Nitrogen oxides	mg	7200
	Hydrogen chloride	mg	150
	Metals	mg	2
	Hydrocarbons	mg	6500
Fuel	Coal	MJ	5.86
	Oil	MJ	3.5
	Gas	MJ	4.76
	Hydro	MJ	0.71
	Nuclear	MJ	5.74
	Other	MJ	0.17
	Total fuels	MJ	20.74
	Total fuel plus feedstock	MJ	20.74
Raw materials	Iron ore	mg	460
	Limestone	mg	10500
	Water	mg	5300000
	Sodium chloride	mg	590000
	Sand	mg	200
Water emissions	COD	mg	13
	BOD	mg	3
	Acids as H+	mg	270
	Metals	mg	70
	Chloride	mg	29000
	Suspended solids	mg	1200
	Dissolved solids	mg	50
	Sulphate	mg	3900
	Sodium	mg	4100
Solid wastes	Industrial waste	mg	1000
	Mineral waste	mg	55000
	Slags & ashes	mg	11000
	Inert chemical	mg	7000
	Regulated chemicals	mg	20

Shaded cells show burdens used in the environmental analysis.

Gross inputs and outputs from production of 1kg PVC resin averaged over all polymerisation processes

Boustead, I (1994) Ecoprofiles of the European Polymer Industry Report 6: Polyvinyl chloride. APME Technical Centre, Brussels

Air emissions	Dust	mg	3900
	Carbon monoxide	mg	2700
	Carbon dioxide	mg	1944000
	Sulphur oxides	mg	13000
	Nitrogen oxides	mg	16000
	Chlorine	mg	2
	Hydrogen chloride	mg	230
	Metals	mg	3
	Chlorinated organics	mg	720
Fuel	Coal	MJ	6.96
	Oil	MJ	6.04
	Gas	MJ	15.41
	Hydro	MJ	0.84
	Nuclear	MJ	7.87
	Other	MJ	0.13
	Total fuels	MJ	37.25
Feedstocks	Oil	MJ	16.85
	Gas	MJ	12.71
	Total feedstock	MJ	29.56
	Total fuel plus feedstock	MJ	66.81
Raw materials	Iron ore	mg	400
	Limestone	mg	1600
	Water	mg	19000000
	Bauxite	mg	220
	Sodium chloride	mg	690000
	Sand	mg	1200
Water emissions	COD	mg	1100
	BOD	mg	80
	Acids as H+	mg	110
	Chloride	mg	40000
	Dissolved organics	mg	1000
	Suspended solids	mg	2400
	Oil	mg	50
	Dissolved solids	mg	500
	Other nitrogen	mg	3
	Chlorinated organics	mg	10
	Sulphate	mg	4300
	Sodium	mg	2300
Solid wastes	Industrial waste	mg	1800
	Mineral waste	mg	66000
	Slags & ashes	mg	47000
	Inert chemical	mg	14000
	Regulated chemicals	mg	1200

Shaded cells show burdens used in the environmental analysis.

Appendix 5.
Environmental burdens of diversion from incineration and landfill

Table 2: Incineration to high quality recycling.

		RIGID			FLEXIBLE		
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator		
Emissions to atmosphere		None	Mass based	Heat based	None	Mass based	Heat based
Methane	kg / tonne of waste	0	-30	-49	0	-30	-60
CO_2	kg / tonne of waste	-3,969	-3,701	-3,535	-3,277	-3,008	-2,741
Dust (taken as all PM_{10})	kg / tonne of waste	-4.46	-4.41	-4.37	-2.80	-2.74	-2.69
NO_x	kg / tonne of waste	-18.03	-17.03	-16.42	-11.55	-10.56	-9.56
SO_2	kg / tonne of waste	-15.79	-15.50	-15.33	-9.92	-9.63	-9.34
HCl	kg / tonne of waste	-0.299	-0.248	-0.216	-0.207	-0.156	-0.105
Cd	kg / tonne of waste	-0.00025	0.00000	0.00016	-0.00025	0.00000	0.00025
Pb and other metals	kg / tonne of waste	-0.0059	-0.0033	-0.0018	-0.0046	-0.0021	0.0005
Dioxin	ug I-TEQ / tonne of waste	-0.506	0.000	0.312	-0.506	0.000	0.505
Energy requirement							
Electricity from incineration	MWh/tonne	0.81	0.31	0.00	1.00	0.50	0.00
Heat from incineration	MWh/tonne	0.81	0.31	0.00	1.00	0.50	0.00
Electricty for recycling	MWh/tonne	4.17	4.17	4.17	4.17	4.17	4.17
APC reagents required							
Lime	kg / tonne of waste	-472	-465	-460	-295	-288	-280
NaOH	kg / tonne of waste	-228	-226	-224	-143	-141	-138
Solid wastes for disposal							
APC residues	kg / tonne of waste	-896	-883	-875	-559	-546	-533
Grate ash	kg / tonne of waste	-7	113	187	-21	99	219
Fly ash	kg / tonne of waste	-16	8	23	-52	-28	-4
From NaOH and PVC manufacture	kg / tonne of waste	-140	-140	-140	-88	-87	-87
Solid waste constituents							
Cadmium in incineration residues	kg / tonne of waste	-0.087	-0.081	-0.076	-0.052	-0.046	-0.039
Cadmium in PVC compound	kg / tonne of waste	0.000	-0.007	-0.012	0.000	-0.007	-0.014
Lead in incineration residues	kg / tonne of waste	-10.6	-10.3	-10.1	-4.4	-4.1	-3.8
Lead in PVC compound	kg / tonne of waste	0.000	-0.455	-0.736	0.000	-0.455	-0.909
Plasticisers in PVC compound	kg / tonne of waste	0	0	0	0	0	0
Resource use							
Water	kg / tonne of waste	-19,250	-19,238	-19,230	-12,018	-12,006	-11,994
Fuels & feedstocks	kg / tonne of waste	-68	-68	-68	-43	-43	-42
Other raw materials	kg / tonne of waste	-792	-791	-790	-495	-494	-493
Discharges to water							
From NaOH and PVC manufacture	kg / tonne of waste	-58	-58	-58	-36	-36	-36

Shaded cells show monetarised burdens used in the environmental analysis.

Table 3: Incineration to low quality recycling.

		RIGID			FLEXIBLE		
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator		
		None	Mass based	Heat based	None	Mass based	Heat based
Emissions to atmosphere							
Methane	kg / tonne of waste	0	-30	-49	0	-30	-60
CO_2	kg / tonne of waste	-2,123	-1,855	-1,689	-2,125	-1,856	-1,589
Dust (taken as all $PM_{10)}$	kg / tonne of waste	-0.76	-0.71	-0.67	-0.49	-0.43	-0.38
NO_x	kg / tonne of waste	-2.84	-1.84	-1.23	-2.07	-1.08	-0.08
SO_2	kg / tonne of waste	-3.45	-3.16	-2.99	-2.21	-1.92	-1.63
HCl	kg / tonne of waste	-0.081	-0.030	0.002	-0.071	-0.020	0.031
Cd	kg / tonne of waste	-0.00025	0.00000	0.00016	-0.00025	0.00000	0.00025
Pb and other metals	kg / tonne of waste	-0.0030	-0.0005	0.0011	-0.0028	-0.0003	0.0022
Dioxin	ug I-TEQ / tonne of waste	-0.506	0.000	0.312	-0.506	0.000	0.505
Energy requirement							
Electricity from incineration	MWh/tonne	0.81	0.31	0.00	1.00	0.50	0.00
Heat from incineration	MWh/tonne	0.81	0.31	0.00	1.00	0.50	0.00
Electricty for recycling	MWh/tonne	2.78	2.78	2.78	2.78	2.78	2.78
APC reagents required							
Lime	kg / tonne of waste	-472	-465	-460	-295	-288	-280
NaOH	kg / tonne of waste	-228	-226	-224	-143	-141	-138
Solid wastes for disposal							
APC residues	kg / tonne of waste	-896	-883	-875	-559	-546	-533
Grate ash	kg / tonne of waste	-7	113	187	-21	99	219
Fly ash	kg / tonne of waste	-16	8	23	-52	-28	-4
From NaOH and PVC manufacture	kg / tonne of waste	-17	-17	-17	-11	-10	-10
Solid waste constituents							
Cadmium in incineration residues	kg / tonne of waste	-0.087	-0.081	-0.076	-0.052	-0.046	-0.039
Cadmium in PVC compound	kg / tonne of waste	0.000	-0.007	-0.012	0.000	-0.007	-0.014
Lead in incineration residues	kg / tonne of waste	-10.6	-10.3	-10.1	-4.4	-4.1	-3.8
Lead in PVC compound	kg / tonne of waste	0.000	-0.455	-0.736	0.000	-0.455	-0.909
Plasticisers in PVC compound	kg / tonne of waste	0	0	0	0	0	0
Resource use							
Water	kg / tonne of waste	-1,208	-1,196	-1,188	-757	-745	-733
Fuels & feedstocks	kg / tonne of waste	-5	-5	-5	-3	-3	-3
Other raw materials	kg / tonne of waste	-134	-133	-132	-84	-83	-82
Discharges to water							
From NaOH and PVC manufacture	kg / tonne of waste	-9	-9	-9	-6	-5	-5

Shaded cells show monetarised burdens used in the environmental analysis.

Table 4: Landfill to high quality recycling.

		RIGID			FLEXIBLE		
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator		
		None	Mass based	Heat based	None	Mass based	Heat based
Emissions to atmosphere							
Methane	kg / tonne of waste	0	0	0	0	0	0
CO_2	kg / tonne of waste	-1,839	-1,839	-1,839	-1,352	-1,352	-1,352
Dust (taken as all PM_{10})	kg / tonne of waste	-3.70	-3.70	-3.70	-2.31	-2.31	-2.31
NO_x	kg / tonne of waste	-15.24	-15.24	-15.24	-9.44	-9.44	-9.44
SO_2	kg / tonne of waste	-12.25	-12.25	-12.25	-7.71	-7.71	-7.71
HCl	kg / tonne of waste	-0.218	-0.218	-0.218	-0.136	-0.136	-0.136
Cd	kg / tonne of waste	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Pb and other metals	kg / tonne of waste	-0.0028	-0.0028	-0.0028	-0.0018	-0.0018	-0.0018
Dioxin	ug I-TEQ / tonne of waste	0.000	0.000	0.000	0.000	0.000	0.000
Energy requirement							
Electricity from incineration	MWh/tonne	0.00	0.00	0.00	0.00	0.00	0.00
Heat from incineration	MWh/tonne	0.00	0.00	0.00	0.00	0.00	0.00
Electricty for recycling	MWh/tonne	4.17	4.17	4.17	4.17	4.17	4.17
APC reagents required							
Lime	kg / tonne of waste	0	0	0	0	0	0
NaOH	kg / tonne of waste	0	0	0	0	0	0
Solid wastes for disposal							
APC residues	kg / tonne of waste	0	0	0	0	0	0
Grate ash	kg / tonne of waste	0	0	0	0	0	0
Fly ash	kg / tonne of waste	0	0	0	0	0	0
From NaOH and PVC manufacture	kg / tonne of waste	-123	-123	-123	-77	-77	-77
Solid waste constituents							
Cadmium in incineration residues	kg / tonne of waste	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium in PVC compound	kg / tonne of waste	-0.095	-0.095	-0.095	-0.059	-0.059	-0.059
Lead in incineration residues	kg / tonne of waste	0.0	0.0	0.0	0.0	0.0	0.0
Lead in PVC compound	kg / tonne of waste	-17.100	-17.100	-17.100	-7.100	-7.100	-7.100
Plasticisers in PVC compound	kg / tonne of waste	0	0	0	-296	-296	-296
Resource use							
Water	kg / tonne of waste	-18,042	-18,042	-18,042	-11,261	-11,261	-11,261
Fuels & feedstocks	kg / tonne of waste	-63	-63	-63	-40	-40	-40
Other raw materials	kg / tonne of waste	-658	-658	-658	-411	-411	-411
Discharges to water							
From NaOH and PVC manufacture	kg / tonne of waste	-49	-49	-49	-31	-31	-31

Shaded cells show monetarised burdens used in the environmental analysis.

Table 5: Landfill to low quality recycling.

		RIGID			FLEXIBLE		
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator		
		None	Mass based	Heat based	None	Mass based	Heat based
Emissions to atmosphere							
Methane	kg / tonne of waste	0	0	0	0	0	0
CO_2	kg / tonne of waste	6.7	6.7	6.7	-200	-200	-200
Dust (taken as all $PM_{10)}$	kg / tonne of waste	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
NO_x	kg / tonne of waste	-0.0494	-0.0494	-0.0494	0.0367	0.0367	0.0367
SO_2	kg / tonne of waste	0.0881	0.0881	0.0881	0.0021	0.0021	0.0021
HCl	kg / tonne of waste	0.000	0.000	0.000	0.000	0.000	0.000
Cd	kg / tonne of waste	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Pb and other metals	kg / tonne of waste	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dioxin	ug I-TEQ / tonne of waste	0.000	0.000	0.000	0.000	0.000	0.000
Energy requirement							
Electricity from incineration	MWh/tonne	0.00	0.00	0.00	0.00	0.00	0.00
Heat from incineration	MWh/tonne	0.00	0.00	0.00	0.00	0.00	0.00
Electricty for recycling	MWh/tonne	2.78	2.78	2.78	2.78	2.78	2.78
APC reagents required							
Lime	kg / tonne of waste	0	0	0	0	0	0
NaOH	kg / tonne of waste	0	0	0	0	0	0
Solid wastes for disposal							
APC residues	kg / tonne of waste	0	0	0	0	0	0
Grate ash	kg / tonne of waste	0	0	0	0	0	0
Fly ash	kg / tonne of waste	0	0	0	0	0	0
From NaOH and PVC manufacture	kg / tonne of waste	0	0	0	0	0	0
Solid waste constituents							
Cadmium in incineration residues	kg / tonne of waste	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium in PVC compound	kg / tonne of waste	-0.095	-0.095	-0.095	-0.059	-0.059	-0.059
Lead in incineration residues	kg / tonne of waste	0.0	0.0	0.0	0.0	0.0	0.0
Lead in PVC compound	kg / tonne of waste	-17.100	-17.100	-17.100	-7.100	-7.100	-7.100
Plasticisers in PVC compound	kg / tonne of waste	0	0	0	-296	-296	-296
Resource use							
Water	kg / tonne of waste	0	0	0	0	0	0
Fuels & feedstocks	kg / tonne of waste	0	0	0	0	0	0
Other raw materials	kg / tonne of waste	0	0	0	0	0	0
Discharges to water							
From NaOH and PVC manufacture	kg / tonne of waste	0	0	0	0	0	0

Shaded cells show monetarised burdens used in the environmental analysis.

Table 6: Incineration to landfill.

		RIGID			FLEXIBLE		
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator		
		None	Mass based	Heat based	None	Mass based	Heat based
Emissions to atmosphere							
Methane	kg / tonne of waste	0	-30	-49	0	-30	-60
CO_2	kg / tonne of waste	-2,130	-1,862	-1,696	-1,925	-1,657	-1,389
Dust (taken as all $PM_{10)}$	kg / tonne of waste	-0.77	-0.71	-0.68	-0.49	-0.44	-0.38
NO_x	kg / tonne of waste	-2.79	-1.79	-1.18	-2.11	-1.11	-0.12
SO_2	kg / tonne of waste	-3.54	-3.25	-3.07	-2.22	-1.92	-1.64
HCl	kg / tonne of waste	-0.081	-0.030	0.002	-0.071	-0.020	0.031
Cd	kg / tonne of waste	-0.00025	0.00000	0.00016	-0.00025	0.00000	0.00025
Pb and other metals	kg / tonne of waste	-0.0030	-0.0005	0.0011	-0.0028	-0.0003	0.0022
Dioxin	ug I-TEQ / tonne of waste	-0.506	0.000	0.312	-0.506	0.000	0.505
Energy requirement							
Electricity from incineration	MWh/tonne	0.81	0.31	0.00	1.00	0.50	0.00
Heat from incineration	MWh/tonne	0.81	0.31	0.00	1.00	0.50	0.00
Electricty for recycling	MWh/tonne	0.00	0.00	0.00	0.00	0.00	0.00
APC reagents required							
Lime	kg / tonne of waste	-472	-465	-460	-295	-288	-280
NaOH	kg / tonne of waste	-228	-226	-224	-143	-141	-138
Solid wastes for disposal							
APC residues	kg / tonne of waste	-896	-883	-875	-559	-546	-533
Grate ash	kg / tonne of waste	-6.60	113.40	187.44	-21.00	99.00	219
Fly ash	kg / tonne of waste	-16.00	8.00	22.81	-52.00	-28.00	-4
From NaOH and PVC manufacture	kg / tonne of waste	-16.90	-16.73	-16.63	-10.60	-10.43	-10
Solid waste constituents							
Cadmium in incineration residues	kg / tonne of waste	-0.087	-0.081	-0.076	-0.052	-0.046	-0.039
Cadmium in PVC compound	kg / tonne of waste	0.095	0.088	0.083	0.059	0.052	0.045
Lead in incineration residues	kg / tonne of waste	-10.6	-10.3	-10.1	-4.4	-4.1	-3.8
Lead in PVC compound	kg / tonne of waste	17.100	16.645	16.364	7.100	6.645	6.191
Plasticisers in PVC compound	kg / tonne of waste	0	0	0	296	296	296
Resource use							
Water	kg / tonne of waste	-1,208	-1,196	-1,188	-757	-745	-733
Fuels & feedstocks	kg / tonne of waste	-4.7	-4.7	-4.7	-3.0	-2.9	-3
Other raw materials	kg / tonne of waste	-134	-133	-132	-84	-83	-82
Discharges to water							
From NaOH and PVC manufacture	kg / tonne of waste	-8.8	-8.7	-8.6	-5.5	-5.4	-5

Shaded cells show monetarised burdens used in the environmental analysis.

Appendix 6.
Cumulative scenario burdens, 2000-2020

Table 7: Environmental burdens, Scenario 1, high incineration future.

		RIGID			FLEXIBLE			RIGID + FLEXIBLE			
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			
Emissions to atmosphere		None	Mass based	Heat based	None	Mass based	Heat based	None	Mass based	Heat based	Mean of R+F
Methane	ktonnes	0	-48	-78	0	-7	-13	0	-55	-91	-49
CO_2	ktonnes	-10,693	-10,261	-9,994	-1,180	-1,121	-1,061	-11,873	-11,381	-11,055	-11,436
Dust (taken as all PM_{10})	ktonnes	-15.8	-15.7	-15.7	-1.4	-1.4	-1.4	-17.2	-17.1	-17.1	-17.1
NO_x	ktonnes	-64.7	-63.1	-62.1	-5.7	-5.5	-5.3	-70.4	-68.6	-67.4	-68.8
SO_2	ktonnes	-54.1	-53.6	-53.3	-4.8	-4.7	-4.7	-58.9	-58.3	-58.0	-58.4
HCl	ktonnes	-0.99	-0.91	-0.86	-0.09	-0.08	-0.07	-1.08	-0.99	-0.93	-1.00
Cd	ktonnes	-0.0004	0.0000	0.0003	-0.0001	0.0000	0.0001	-0.0005	0.0000	0.0003	-0.0001
Pb and other metals	ktonnes	-0.0161	-0.0120	-0.0095	-0.0016	-0.0011	-0.0005	-0.0177	-0.0131	-0.0100	-0.0136
Dioxin	g I-TEQ	-0.815	0.000	0.503	-0.112	0.000	0.112	-0.927	0.000	0.615	-0.104
Energy requirement											
Electricity from incineration	TWh	1.302	0.497	0.000	0.221	0.111	0.000	1.523	0.607	0.000	0.710
Heat from incineration	TWh	1.302	0.497	0.000	0.221	0.111	0.000	1.523	0.607	0.000	0.710
Electricty for recycling	TWh	16.45	16.45	16.45	2.33	2.33	2.33	18.78	18.78	18.78	18.78
APC reagents required											
Lime	ktonnes	-760	-749	-741	-65	-64	-62	-826	-812	-803	-814
NaOH	ktonnes	-367	-364	-361	-32	-31	-31	-399	-395	-392	-395
Solid wastes for disposal											
APC residues	ktonnes	-1,443	-1,422	-1,409	-124	-121	-118	-1,567	-1,543	-1,527	-1,546
Grate ash	ktonnes	-11	183	302	-5	22	48	-15	205	350	180
Fly ash	ktonnes	-26	13	37	-11	-6	-1	-37	7	36	2
From NaOH and PVC manufacture	ktonnes	-515	-514	-514	-45	-45	-45	-560	-560	-559	-560
Solid waste constituents											
Cadmium in incineration residues	ktonnes	-0.14	-0.13	-0.12	-0.01	-0.01	-0.01	-0.15	-0.14	-0.13	-0.14
Cadmium in PVC compound	ktonnes	-0.22	-0.23	-0.24	-0.02	-0.02	-0.02	-0.24	-0.26	-0.26	-0.25
Lead in incineration residues	ktonnes	-17	-17	-16	-1	-1	-1	-18	-17	-17	-18
Lead in PVC compound	ktonnes	-40	-41	-41	-2	-3	-3	-42	-43	-44	-43
Plasticisers in PVC compound	ktonnes	0	0	0	-100	-100	-100	-100	-100	-100	-100
Resource use											
Water	ktonnes	-73,176	-73,156	-73,144	-6,451	-6,448	-6,446	-79,627	-79,605	-79,590	-79,607
Fuels & feedstocks	ktonnes	-258	-258	-258	-23	-23	-23	-281	-281	-281	-281
Other raw materials	ktonnes	-2,816	-2,813	-2,812	-248	-248	-247	-3,064	-3,061	-3,059	-3,061
Discharges to water											
From NaOH and PVC manufacture	ktonnes	-209	-208	-208	-18	-18	-18	-227	-227	-227	-227

shaded cells show monetarised burdens used in the environmental analysis.

Table 8: Environmental burdens, Scenario 1, low incineration future.

		RIGID			FLEXIBLE			RIGID + FLEXIBLE			
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			
Emissions to atmosphere		None	Mass based	Heat based	None	Mass based	Heat based	None	Mass based	Heat based	Mean of R+F
Methane	ktonnes	0	-42	-68	0	-6	-12	0	-48	-80	-43
CO_2	ktonnes	-10,254	-9,877	-9,645	-1,124	-1,073	-1,021	-11,378	-10,950	-10,666	-10,998
Dust (taken as all PM_{10})	ktonnes	-15.7	-15.6	-15.5	-1.4	-1.4	-1.4	-17.1	-17.0	-16.9	-17.0
NO_x	ktonnes	-64.1	-62.7	-61.8	-5.7	-5.5	-5.3	-69.8	-68.2	-67.1	-68.3
SO_2	ktonnes	-53.3	-52.9	-52.7	-4.7	-4.7	-4.6	-58.1	-57.6	-57.3	-57.7
HCl	ktonnes	-0.98	-0.90	-0.86	-0.09	-0.08	-0.07	-1.07	-0.98	-0.93	-0.99
Cd	ktonnes	-0.0004	0.0000	0.0002	0.0000	0.0000	0.0000	-0.0004	0.0000	0.0003	0.0000
Pb and other metals	ktonnes	-0.0155	-0.0119	-0.0097	-0.0015	-0.0010	-0.0006	-0.0170	-0.0130	-0.0103	-0.0134
Dioxin	g I-TEQ	-0.711	0.000	0.439	-0.097	0.000	0.097	-0.808	0.000	0.536	-0.091
Energy requirement											
Electricity from incineration	TWh	1.136	0.433	0.000	0.192	0.096	0.000	1.328	0.529	0.000	0.619
Heat from incineration	TWh	1.136	0.433	0.000	0.192	0.096	0.000	1.328	0.529	0.000	0.619
Electricty for recycling	TWh	16.45	16.45	16.45	2.33	2.33	2.33	18.78	18.78	18.78	18.78
APC reagents required											
Lime	ktonnes	-663	-653	-647	-57	-55	-54	-720	-708	-701	-710
NaOH	ktonnes	-320	-317	-315	-27	-27	-27	-348	-344	-342	-345
Solid wastes for disposal											
APC residues	ktonnes	-1,259	-1,240	-1,229	-107	-105	-102	-1,366	-1,345	-1,331	-1,348
Grate ash	ktonnes	-9	159	263	-4	19	42	-13	178	305	157
Fly ash	ktonnes	-22	11	32	-10	-5	-1	-32	6	31	2
From NaOH and PVC manufacture	ktonnes	-511	-511	-511	-45	-45	-45	-556	-556	-556	-556
Solid waste constituents											
Cadmium in incineration residues	ktonnes	-0.12	-0.11	-0.11	-0.01	-0.01	-0.01	-0.13	-0.12	-0.11	-0.12
Cadmium in PVC compound	ktonnes	-0.24	-0.25	-0.26	-0.02	-0.02	-0.02	-0.26	-0.27	-0.28	-0.27
Lead in incineration residues	ktonnes	-14.9	-14.5	-14.2	-0.84	-0.79	-0.74	-15.71	-15.25	-14.95	-15.30
Lead in PVC compound	ktonnes	-43.5	-44.1	-44.5	-2.6	-2.7	-2.8	-46.1	-46.8	-47.3	-46.7
Plasticisers in PVC compound	ktonnes	0.0	0.0	0.0	-108.8	-108.8	-108.8	-108.8	-108.8	-108.8	-108.8
Resource use											
Water	ktonnes	-72,927	-72,910	-72,900	-6,429	-6,427	-6,424	-79,356	-79,337	-79,324	-79,339
Fuels & feedstocks	ktonnes	-257	-257	-257	-23	-23	-23	-280	-280	-280	-280
Other raw materials	ktonnes	-2,788	-2,786	-2,785	-246	-245	-245	-3,033	-3,031	-3,030	-3,032
Discharges to water											
From NaOH and PVC manufacture	ktonnes	-207	-207	-207	-18	-18	-18	-225	-225	-225	-225

shaded cells show monetarised burdens used in the environmental analysis.

Table 9: Environmental burdens, Scenario 2, high incineration future.

		RIGID			FLEXIBLE			RIGID + FLEXIBLE			
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			
Emissions to atmosphere		None	Mass based	Heat based	None	Mass based	Heat based	None	Mass based	Heat based	Mean of R+F
Methane	ktonnes	0	-80	-130	0	-42	-83	0	-122	-213	-112
CO_2	ktonnes	-16,819	-16,100	-15,656	-5,477	-5,103	-4,730	-22,296	-21,203	-20,386	-21,295
Dust (taken as all $PM_{10)}$)	ktonnes	-24.4	-24.2	-24.1	-4.9	-4.8	-4.8	-29.3	-29.1	-28.9	-29.1
NO_x	ktonnes	-99.6	-96.9	-95.2	-20.3	-18.9	-17.5	-119.8	-115.7	-112.7	-116.1
SO_2	ktonnes	-83.5	-82.7	-82.2	-17.3	-16.9	-16.5	-100.7	-99.6	-98.7	-99.7
HCl	ktonnes	-1.54	-1.40	-1.31	-0.35	-0.28	-0.21	-1.89	-1.68	-1.52	-1.69
Cd	ktonnes	-0.0007	0.0000	0.0004	-0.0004	0.0000	0.0004	-0.0010	0.0000	0.0008	-0.0001
Pb and other metals	ktonnes	-0.0253	-0.0185	-0.0143	-0.0072	-0.0037	-0.0002	-0.0325	-0.0222	-0.0145	-0.0231
Dioxin	g I-TEQ	-1.357	0.000	0.837	-0.704	0.000	0.703	-2.061	0.000	1.540	-0.174
Energy requirement											
Electricity from incineration	TWh	2.168	0.827	0.000	1.392	0.696	0.001	3.560	1.523	0.001	1.695
Heat from incineration	TWh	2.168	0.827	0.000	1.392	0.696	0.001	3.560	1.523	0.001	1.695
Electricty for recycling	TWh	26.11	26.11	26.11	11.98	11.98	11.98	38.08	38.08	38.08	38.08
APC reagents required											
Lime	ktonnes	-1,265	-1,246	-1,234	-411	-401	-390	-1,676	-1,647	-1,624	-1,649
NaOH	ktonnes	-611	-605	-601	-199	-196	-193	-810	-801	-794	-802
Solid wastes for disposal											
APC residues	ktonnes	-2,402	-2,367	-2,345	-778	-760	-742	-3,180	-3,127	-3,087	-3,131
Grate ash	ktonnes	-18	304	503	-29	138	305	-47	442	807	401
Fly ash	ktonnes	-43	21	61	-72	-39	-6	-115	-18	56	-26
From NaOH and PVC manufacture	ktonnes	-791	-791	-790	-157	-156	-156	-948	-947	-946	-947
Solid waste constituents											
Cadmium in incineration residues	ktonnes	-0.23	-0.22	-0.21	-0.07	-0.06	-0.05	-0.31	-0.28	-0.26	-0.28
Cadmium in PVC compound	ktonnes	-0.35	-0.37	-0.38	-0.12	-0.13	-0.14	-0.47	-0.50	-0.52	-0.50
Lead in incineration residues	ktonnes	-28	-28	-27	-6	-6	-5	-34	-33	-32	-33
Lead in PVC compound	ktonnes	-63	-64	-65	-14	-15	-15	-77	-79	-81	-79
Plasticisers in PVC compound	ktonnes	0	0	0	-592	-592	-592	-592	-592	-592	-592
Resource use											
Water	ktonnes	-112,230	-112,198	-112,178	-21,774	-21,757	-21,740	-134,004	-133,955	-133,918	-133,959
Fuels & feedstocks	ktonnes	-396	-396	-396	-77	-77	-77	-473	-473	-473	-473
Other raw materials	ktonnes	-4,337	-4,333	-4,331	-874	-872	-870	-5,211	-5,205	-5,201	-5,206
Discharges to water											
From NaOH and PVC manufacture	ktonnes	-321	-321	-321	-64	-64	-64	-385	-385	-385	-385

Shaded cells show monetarised burdens used in the environmental analysis.

Table 10: Environmental burdens, Scenario 2, low incineration future.

		RIGID			FLEXIBLE			RIGID + FLEXIBLE			
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			
Emissions to atmosphere		None	Mass based	Heat based	None	Mass based	Heat based	None	Mass based	Heat based	Mean of R+F
Methane	ktonnes	0	-70	-114	0	-36	-72	0	-106	-186	-97
CO_2	ktonnes	-16,104	-15,474	-15,086	-5,113	-4,790	-4,468	-21,217	-20,265	-19,554	-20,345
Dust (taken as all PM_{10})	ktonnes	-24.1	-24.0	-23.9	-4.8	-4.8	-4.7	-29.0	-28.8	-28.6	-28.8
NO_x	ktonnes	-98.6	-96.3	-94.8	-19.9	-18.7	-17.5	-118.5	-114.9	-112.3	-115.2
SO_2	ktonnes	-82.3	-81.6	-81.2	-16.8	-16.5	-16.1	-99.1	-98.1	-97.3	-98.2
HCl	ktonnes	-1.51	-1.39	-1.31	-0.34	-0.27	-0.21	-1.85	-1.66	-1.53	-1.68
Cd	ktonnes	-0.0006	0.0000	0.0004	-0.0003	0.0000	0.0003	-0.0009	0.0000	0.0007	-0.0001
Pb and other metals	ktonnes	-0.0243	-0.0184	-0.0147	-0.0067	-0.0036	-0.0006	-0.0310	-0.0220	-0.0153	-0.0228
Dioxin	g I-TEQ	-1.187	0.000	0.732	-0.609	0.000	0.608	-1.795	0.000	1.340	-0.152
Energy requirement											
Electricity from incineration	TWh	1.896	0.723	0.000	1.203	0.602	0.001	3.099	1.325	0.001	1.475
Heat from incineration	TWh	1.896	0.723	0.000	1.203	0.602	0.001	3.099	1.325	0.001	1.475
Electricty for recycling	TWh	26.11	26.11	26.11	11.98	11.98	11.98	38.08	38.08	38.08	38.08
APC reagents required											
Lime	ktonnes	-1,107	-1,090	-1,079	-355	-346	-337	-1,462	-1,436	-1,417	-1,438
NaOH	ktonnes	-535	-529	-526	-172	-169	-167	-707	-699	-693	-699
Solid wastes for disposal											
APC residues	ktonnes	-2,101	-2,070	-2,051	-672	-657	-641	-2,774	-2,727	-2,692	-2,731
Grate ash	ktonnes	-15	266	440	-25	119	263	-41	385	703	349
Fly ash	ktonnes	-38	19	53	-63	-34	-5	-100	-15	49	-22
From NaOH and PVC manufacture	ktonnes	-785	-785	-785	-155	-154	-154	-940	-939	-939	-939
Solid waste constituents											
Cadmium in incineration residues	ktonnes	-0.20	-0.19	-0.18	-0.06	-0.05	-0.05	-0.27	-0.24	-0.23	-0.25
Cadmium in PVC compound	ktonnes	-0.38	-0.40	-0.41	-0.13	-0.14	-0.15	-0.51	-0.54	-0.56	-0.54
Lead in incineration residues	ktonnes	-25	-24	-24	-5	-5	-5	-30	-29	-28	-29
Lead in PVC compound	ktonnes	-69	-70	-71	-16	-16	-17	-84	-86	-87	-86
Plasticisers in PVC compound	ktonnes	0	0	0	-649	-649	-649	-649	-649	-649	-649
Resource use											
Water	ktonnes	-111,824	-111,796	-111,779	-21,631	-21,616	-21,602	-133,455	-133,412	-133,380	-133,416
Fuels & feedstocks	ktonnes	-394	-394	-394	-76	-76	-76	-471	-471	-470	-471
Other raw materials	ktonnes	-4,292	-4,289	-4,287	-858	-856	-855	-5,150	-5,145	-5,141	-5,145
Discharges to water											
From NaOH and PVC manufacture	ktonnes	-318	-318	-318	-63	-63	-63	-381	-381	-381	-381

Shaded cells show monetarised burdens used in the environmental analysis.

Table 11: Environmental burdens, Scenario 3, high incineration future.

		RIGID			FLEXIBLE			RIGID + FLEXIBLE			
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			
Emissions to atmosphere		None	Mass based	Heat based	None	Mass based	Heat based	None	Mass based	Heat based	Mean of R+F
Methane	ktonnes	0	-132	-214	0	-200	-399	0	-332	-613	-315
CO_2	ktonnes	-9,389	-8,206	-7,476	-12,812	-11,026	-9,244	-22,201	-19,232	-16,720	-19,384
Dust (taken as all $PM_{10)}$	ktonnes	-3.4	-3.1	-3.0	-3.3	-2.9	-2.5	-6.7	-6.0	-5.5	-6.1
NO_x	ktonnes	-12.3	-7.9	-5.2	-14.0	-7.4	-0.8	-26.4	-15.3	-5.9	-15.9
SO_2	ktonnes	-15.6	-14.3	-13.5	-14.7	-12.8	-10.9	-30.4	-27.1	-24.4	-27.3
HCl	ktonnes	-0.36	-0.13	0.01	-0.47	-0.13	0.21	-0.83	-0.26	0.22	-0.29
Cd	ktonnes	-0.0011	0.0000	0.0007	-0.0017	0.0000	0.0017	-0.0028	0.0000	0.0024	-0.0001
Pb and other metals	ktonnes	-0.0134	-0.0022	0.0047	-0.0188	-0.0020	0.0149	-0.0322	-0.0041	0.0196	-0.0056
Dioxin	g I-TEQ	-2.230	0.000	1.376	-3.368	0.000	3.361	-5.598	0.000	4.737	-0.287
Energy requirement											
Electricity from incineration	TWh	3.564	1.360	0.000	6.656	3.328	0.007	10.220	4.688	0.007	4.971
Heat from incineration	TWh	3.564	1.360	0.000	6.656	3.328	0.007	10.220	4.688	0.007	4.971
Electricty for recycling	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
APC reagents required											
Lime	ktonnes	-2,081	-2,049	-2,029	-1,964	-1,915	-1,867	-4,044	-3,964	-3,896	-3,968
NaOH	ktonnes	-1,005	-995	-989	-952	-937	-921	-1,957	-1,931	-1,910	-1,933
Solid wastes for disposal											
APC residues	ktonnes	-3,950	-3,892	-3,856	-3,721	-3,633	-3,546	-7,670	-7,525	-7,402	-7,532
Grate ash	ktonnes	-29	500	826	-140	659	1,456	-169	1,159	2,282	1,091
Fly ash	ktonnes	-71	35	101	-346	-186	-27	-417	-151	74	-165
From NaOH and PVC manufacture	ktonnes	-74	-74	-73	-71	-69	-68	-145	-143	-142	-143
Solid waste constituents											
Cadmium in incineration residues	ktonnes	-0.38	-0.35	-0.34	-0.35	-0.30	-0.26	-0.73	-0.66	-0.60	-0.66
Cadmium in PVC compound	ktonnes	0.42	0.39	0.37	0.39	0.34	0.30	0.81	0.73	0.66	0.74
Lead in incineration residues	ktonnes	-47	-45	-45	-29	-27	-25	-76	-73	-70	-73
Lead in PVC compound	ktonnes	75	73	72	47	44	41	123	118	113	118
Plasticisers in PVC compound	ktonnes	0	0	0	1,973	1,973	1,973	1,973	1,973	1,973	1,973
Resource use											
Water	ktonnes	-5,325	-5,272	-5,239	-5,039	-4,958	-4,878	-10,363	-10,230	-10,116	-10,236
Fuels & feedstocks	ktonnes	-21	-21	-21	-20	-19	-19	-41	-40	-40	-40
Other raw materials	ktonnes	-591	-585	-581	-562	-553	-544	-1,152	-1,138	-1,125	-1,138
Discharges to water											
From NaOH and PVC manufacture	ktonnes	-39	-38	-38	-37	-36	-36	-76	-75	-74	-75

Shaded cells show monetarised burdens used in the environmental analysis.

Table 12: Environmental burdens, Scenario 3, low incineration future.

		RIGID			FLEXIBLE			RIGID + FLEXIBLE			
		Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			Replacement basis of MSW for PVC at incinerator			
Emissions to atmosphere		**None**	**Mass based**	**Heat based**	**None**	**Mass based**	**Heat based**	**None**	**Mass based**	**Heat based**	**Mean of R+F**
Methane	ktonnes	0	-115	-186	0	-172	-344	0	-287	-530	-272
CO_2	ktonnes	-8,149	-7,122	-6,489	-11,059	-9,517	-7,979	-19,208	-16,640	-14,468	-16,772
Dust (taken as all $PM_{10)}$	ktonnes	-2.9	-2.7	-2.6	-2.8	-2.5	-2.2	-5.8	-5.2	-4.8	-5.3
NO_x	ktonnes	-10.7	-6.9	-4.5	-12.1	-6.4	-0.7	-22.8	-13.2	-5.2	-13.7
SO_2	ktonnes	-13.6	-12.4	-11.8	-12.7	-11.1	-9.4	-26.3	-23.5	-21.2	-23.6
HCl	ktonnes	-0.31	-0.11	0.01	-0.41	-0.11	0.18	-0.72	-0.23	0.19	-0.25
Cd	ktonnes	-0.0010	0.0000	0.0006	-0.0015	0.0000	0.0015	-0.0024	0.0000	0.0020	-0.0001
Pb and other metals	ktonnes	-0.0116	-0.0019	0.0041	-0.0163	-0.0017	0.0128	-0.0279	-0.0036	0.0169	-0.0048
Dioxin	g I-TEQ	-1.936	0.000	1.194	-2.907	0.000	2.901	-4.843	0.000	4.096	-0.249
Energy requirement											
Electricity from incineration	TWh	3.093	1.180	0.000	5.745	2.873	0.006	8.838	4.053	0.006	4.299
Heat from incineration	TWh	3.093	1.180	0.000	5.745	2.873	0.006	8.838	4.053	0.006	4.299
Electricty for recycling	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
APC reagents required											
Lime	ktonnes	-1,806	-1,778	-1,761	-1,695	-1,653	-1,611	-3,501	-3,431	-3,372	-3,435
NaOH	ktonnes	-872	-864	-858	-822	-808	-795	-1,694	-1,672	-1,653	-1,673
Solid wastes for disposal											
APC residues	ktonnes	-3,428	-3,378	-3,347	-3,211	-3,136	-3,061	-6,640	-6,514	-6,407	-6,520
Grate ash	ktonnes	-25.3	433.9	717.1	-120.6	568.8	1,256.8	-145.9	1,002.6	1,973.9	943.5
Fly ash	ktonnes	-61.2	30.6	87.3	-298.7	-160.9	-23.3	-360.0	-130.3	64.0	-142.1
From NaOH and PVC manufacture	ktonnes	-64.7	-64.0	-63.6	-60.9	-59.9	-58.9	-125.6	-123.9	-122.6	-124.0
Solid waste constituents											
Cadmium in incineration residues	ktonnes	-0.33	-0.31	-0.29	-0.30	-0.26	-0.22	-0.63	-0.57	-0.52	-0.57
Cadmium in PVC compound	ktonnes	0.36	0.34	0.32	0.34	0.30	0.26	0.70	0.63	0.58	0.64
Lead in incineration residues	ktonnes	-40	-39	-39	-25	-24	-22	-66	-63	-61	-63
Lead in PVC compound	ktonnes	65	64	63	41	38	36	106	102	98	102
Plasticisers in PVC compound	ktonnes	0	0	0	1,703	1,703	1,703	1,703	1,703	1,703	1,703
Resource use											
Water	ktonnes	-4,622	-4,576	-4,547	-4,349	-4,279	-4,210	-8,971	-8,855	-8,757	-8,861
Fuels & feedstocks	ktonnes	-18	-18	-18	-17	-17	-16	-35	-35	-34	-35
Other raw materials	ktonnes	-513	-508	-504	-485	-477	-469	-998	-985	-974	-985
Discharges to water											
From NaOH and PVC manufacture	ktonnes	-34	-33	-33	-32	-31	-31	-65	-64	-64	-65

Shaded cells show monetarised burdens used in the environmental analysis.

Appendix 7.
Financial costs of the scenarios.

Table 13: Present value avoided costs of diversion of PVC waste from incineration and landfill to recycling. Cumulative costs over 2000 to 2020 and annualised costs at 0, 2, 4 and 6% discount rates.

AVOIDED INCINERATION SUBSIDY																								
	Discount rate		**0%**				**Discount rate**		**2%**				**Discount rate**		**4%**				**Discount rate**		**6%**			
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Rigid PVC	-266	-232	-442	-387	-727	-631	-205	-179	-342	-299	-562	-488	-161	-141	-268	-235	-441	-383	-128	-112	-213	-187	-351	-304
Flexible PVC	-19	-16	-118	-102	-566	-488	-15	-13	-91	-79	-437	-378	-11	-10	-72	-62	-343	-296	-9	-8	-57	-49	-273	-235
Total	**-285**	**-248**	**-561**	**-489**	**-1293**	**-1120**	**-220**	**-192**	**-434**	**-378**	**-1000**	**-866**	**-173**	**-150**	**-340**	**-297**	**-784**	**-679**	**-137**	**-120**	**-270**	**-236**	**-623**	**-540**
Annualised costs, million € /year																								
Rigid PVC	-13.3	-11.6	-22.1	-19.3	-36.4	-31.6	-12.6	-11.0	-20.9	-18.3	-34.4	-29.8	-11.9	-10.3	-19.7	-17.3	-32.4	-28.2	-11.2	-9.7	-18.6	-16.3	-30.6	-26.5
Flexible PVC	-0.9	-0.8	-5.9	-5.1	-28.3	-24.4	-0.9	-0.8	-5.6	-4.8	-26.7	-23.1	-0.8	-0.7	-5.3	-4.6	-25.2	-21.8	-0.8	-0.7	-5.0	-4.3	-23.8	-20.5
Total	**-14.2**	**-12.4**	**-28.0**	**-24.5**	**-64.7**	**-56.0**	**-13.5**	**-11.7**	**-26.5**	**-23.1**	**-61.1**	**-52.9**	**-12.7**	**-11.1**	**-25.0**	**-21.8**	**-57.7**	**-49.9**	**-12.0**	**-10.4**	**-23.6**	**-20.6**	**-54.3**	**-47.1**
AVOIDED INCINERATION CHARGES																								
	Discount rate		0%				Discount rate		2%				Discount rate		4%				Discount rate		6%			
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Rigid PVC	-266	-232	-442	-387	-727	-631	-205	-179	-342	-299	-562	-488	-161	-141	-268	-235	-441	-383	-128	-112	-213	-187	-351	-304
Flexible PVC	-36	-32	-230	-198	-1098	-948	-28	-24	-178	-153	-849	-733	-22	-19	-139	-120	-666	-575	-18	-15	-111	-96	-529	-457
Total	**-302**	**-263**	**-672**	**-585**	**-1826**	**-1579**	**-234**	**-204**	**-520**	**-453**	**-1411**	**-1221**	**-183**	**-160**	**-407**	**-355**	**-1107**	**-957**	**-146**	**-127**	**-324**	**-282**	**-880**	**-761**
Annualised costs, million € /year																								
Rigid PVC	-13.3	-11.6	-22.1	-19.3	-36.4	-31.6	-12.6	-11.0	-20.9	-18.3	-34.4	-29.8	-11.9	-10.3	-19.7	-17.3	-32.4	-28.2	-11.2	-9.7	-18.6	-16.3	-30.6	-26.5
Flexible PVC	-1.8	-1.6	-11.5	-9.9	-54.9	-47.4	-1.7	-1.5	-10.9	-9.4	-51.9	-44.8	-1.6	-1.4	-10.2	-8.9	-49.0	-42.3	-1.5	-1.3	-9.7	-8.3	-46.2	-39.8
Total	**-15.1**	**-13.2**	**-33.6**	**-29.3**	**-91.3**	**-79.0**	**-14.3**	**-12.5**	**-31.8**	**-27.7**	**-86.3**	**-74.7**	**-13.5**	**-11.8**	**-30.0**	**-26.1**	**-81.4**	**-70.5**	**-12.7**	**-11.1**	**-28.2**	**-24.6**	**-76.7**	**-66.4**
AVOIDED LANDFILL CHARGES																								
	Discount rate		0%				Discount rate		2%				Discount rate		4%				Discount rate		6%			
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Rigid PVC	-234	-254	-370	-403			-181	-197	-286	-312			-142	-154	-224	-244			-113	-123	-178	-194		
Flexible PVC	-34	-37	-200	-219			-26	-28	-154	-169			-20	-22	-121	-133			-16	-18	-96	-105		
Total	-268	-291	-569	-622			-207	-225	-440	-481			-162	-176	-345	-377			-129	-140	-275	-300		
Annualised costs, million € /year																								
Rigid PVC	-12	-13	-18	-20			-11	-12	-17	-19			-10	-11	-16	-18			-10	-11	-16	-17		
Flexible PVC	-2	-2	-10	-11			-2	-2	-9	-10			-2	-2	-9	-10			-1	-2	-8	-9		
Total	-13	-15	-28	-31			-13	-14	-27	-29			-12	-13	-25	-28			-11	-12	-24	-26		

Table 14: Present value incurred costs of diversion of PVC waste from incineration to landfill (scenario 3). Cumulative costs over 2000 to 2020 and annualised costs at 0, 2, 4 and 6% discount rates.

INCURRED CHARGES FOR SORTING FOR LANDFILLING																								
	Discount rate		0%				Discount rate		2%				Discount rate		4%				Discount rate		6%			
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Rigid PVC					132	115					102	89					80	70					64	55
Flexible PVC					200	172					154	133					121	104					96	83
Total					**332**	**287**					**257**	**222**					**201**	**174**					**160**	**138**
Annualised costs, million €/year																								
Rigid PVC					6.6	5.7					6.3	5.4					5.9	5.1					5.6	4.8
Flexible PVC					10.0	8.6					9.4	8.1					8.9	7.7					8.4	7.2
Total					**16.6**	**14.4**					**15.7**	**13.6**					**14.8**	**12.8**					**14.0**	**12.1**
INCURRED LANDFILL CHARGES																								
	Discount rate		0%				Discount rate		2%				Discount rate		4%				Discount rate		6%			
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Rigid PVC					441	383					341	296					267	232					213	184
Flexible PVC					666	574					515	444					404	348					321	277
Total					**1106**	**957**					**855**	**740**					**671**	**580**					**533**	**461**
Annualised costs, million €/year																								
Rigid PVC					22.0	19.1					20.8	18.1					19.7	17.1					18.5	16.1
Flexible PVC					33.3	28.7					31.5	27.2					29.7	25.6					28.0	24.1
Total					**55.3**	**47.9**					**52.3**	**45.3**					**49.4**	**42.7**					**46.5**	**40.2**

Table 15: Present value incurred costs of diversion of PVC waste from incineration and landfill recycling (scenarios 1 & 2). Cumulative costs over 2000 to 2020 and annualised costs at 0, 2, 4 and 6% discount rates.

INCURRED CHARGES FOR RECYCLING																								
	Incurred recycling charges 2000-2020						**Incurred recycling charges 2000-2020**						**Incurred recycling charges 2000-2020**						**Incurred recycling charges 2000-2020**					
	Discount rate		0%				Discount rate		2%				Discount rate		4%				Discount rate		6%			
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Rigid construction, HCR	987	987	1213	1213			763	763	938	938			598	598	735	735			476	476	585	585		
Rigid packaging, HCR	0	0	292	292			0	0	225	225			0	0	177	177			0	0	141	141		
Rigid H&C, LQR	0	0	1183	1183			0	0	915	915			0	0	717	717			0	0	570	570		
Flexible cables LQR	0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0		
Flexible flooring, HQR	195	195	276	276			151	151	213	213			119	119	167	167			94	94	133	133		
Flexible hoses & profiles, HQR	0	0	189	189			0	0	146	146			0	0	114	114			0	0	91	91		
Flexible H&C, HQR	0	0	580	580			0	0	449	449			0	0	352	352			0	0	280	280		
Flexible E&E, LQR	0	0	1103	1103			0	0	853	853			0	0	669	669			0	0	532	532		
Rigid PVC	**987**	**987**	**2688**	**2688**			**763**	**763**	**2078**	**2078**			**598**	**598**	**1629**	**1629**			**476**	**476**	**1296**	**1296**		
Flexible PVC	**195**	**195**	**2148**	**2148**			**151**	**151**	**1661**	**1661**			**119**	**119**	**1302**	**1302**			**94**	**94**	**1036**	**1036**		
Total	**1183**	**1183**	**4836**	**4836**			**914**	**914**	**3738**	**3738**			**717**	**717**	**2932**	**2932**			**570**	**570**	**2331**	**2331**		
Annualised costs, million € /year																								
Rigid construction, HCR	49.4	49.4	60.6	60.6			46.7	46.7	57.3	57.3			44.0	44.0	54.1	54.1			41.5	41.5	51.0	51.0		
Rigid packaging, HCR	0.0	0.0	14.6	14.6			0.0	0.0	13.8	13.8			0.0	0.0	13.0	13.0			0.0	0.0	12.3	12.3		
Rigid H&C, LQR	0.0	0.0	59.2	59.2			0.0	0.0	55.9	55.9			0.0	0.0	52.8	52.8			0.0	0.0	49.7	49.7		
Flexible cables LQR	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0		
Flexible flooring, HQR	9.8	9.8	13.8	13.8			9.2	9.2	13.0	13.0			8.7	8.7	12.3	12.3			8.2	8.2	11.6	11.6		
Flexible hoses & profiles, HQR	0.0	0.0	9.4	9.4			0.0	0.0	8.9	8.9			0.0	0.0	8.4	8.4			0.0	0.0	7.9	7.9		
Flexible H&C, HQR	0.0	0.0	29.0	29.0			0.0	0.0	27.4	27.4			0.0	0.0	25.9	25.9			0.0	0.0	24.4	24.4		
Flexible E&E, LQR	0.0	0.0	55.2	55.2			0.0	0.0	52.2	52.2			0.0	0.0	49.2	49.2			0.0	0.0	46.4	46.4		
Rigid PVC	**49.4**	**49.4**	**134.4**	**134.4**			**46.7**	**46.7**	**127.1**	**127.1**			**44.0**	**44.0**	**119.9**	**119.9**			**41.5**	**41.5**	**113.0**	**113.0**		
Flexible PVC	**9.8**	**9.8**	**107.4**	**107.4**			**9.2**	**9.2**	**101.6**	**101.6**			**8.7**	**8.7**	**95.8**	**95.8**			**8.2**	**8.2**	**90.3**	**90.3**		
Total	**59.1**	**59.1**	**241.8**	**241.8**			**55.9**	**55.9**	**228.6**	**228.6**			**52.8**	**52.8**	**215.7**	**215.7**			**49.7**	**49.7**	**203.2**	**203.2**		

Table 16: Present value net cost of the scenarios, cumulative costs over 2000-2020 at 0, 2, 4 and 6% discount rates.

	NET COSTS																							
	Excluding incinerator subsidy																							
	Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Discount rate	**0%**						**2%**						**4%**						**6%**					
Rigid	488	501	1876	1897	-154	-134	377	387	1450	1467	-119	-104	296	304	1137	1150	-94	-81	235	241	904	915	-74	-65
Flexible	125	127	1719	1731	-233	-201	97	98	1329	1338	-180	-155	76	77	1042	1049	-141	-122	60	61	828	834	-112	-97
Total	613	628	3594	3628	-387	-335	474	486	2779	2805	-299	-259	372	381	2179	2200	-235	-203	295	303	1733	1749	-187	-161
	NET COSTS																							
	Including incinerator subsidy																							
	Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3	
Total costs, million €	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Discount rate	**0%**						**2%**						**4%**						**6%**					
Rigid	222	269	1433	1511	-882	-765	171	208	1108	1168	-682	-592	134	163	869	916	-534	-464	107	130	691	728	-425	-369
Flexible	107	111	1600	1629	-799	-689	82	86	1237	1259	-617	-533	65	67	970	987	-484	-418	51	53	771	785	-385	-332
Total	328	380	3033	3139	-1680	-1455	254	294	2345	2427	-1299	-1125	199	230	1839	1903	-1019	-882	158	183	1462	1513	-810	-701

Table 17: Annualised present value net cost of the scenarios, over 2000-2020 at 0, 2, 4 and 6% discount rates.

	NET COSTS																							
	Excluding incinerator subsidy																							
	Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3	
Annualised costs, million € /year	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Discount rate	**0%**						**2%**						**4%**						**6%**					
Rigid	24	25	94	95	-8	-7	23	24	89	90	-7	-6	22	22	84	85	-7	-6	20	21	79	80	-6	-6
Flexible	6	6	86	87	-12	-10	6	6	81	82	-11	-10	6	6	77	77	-10	-9	5	5	72	73	-10	-8
Total	31	31	180	181	-19	-17	29	30	170	172	-18	-16	27	28	160	162	-17	-15	26	26	151	153	-16	-14
	NET COSTS																							
	Including incinerator subsidy																							
	Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3		Scenario 1		Scenario 2		Scenario 3	
Annualised costs, million € /year	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Discount rate	**0%**						**2%**						**4%**						**6%**					
Rigid	11	13	72	76	-44	-38	10	13	68	71	-42	-36	10	12	64	67	-39	-34	9	11	60	63	-37	-32
Flexible	5	6	80	81	-40	-34	5	5	76	77	-38	-33	5	5	71	73	-36	-31	4	5	67	68	-34	-29
Total	16	19	152	157	-84	-73	16	18	143	148	-79	-69	15	17	135	140	-75	-65	14	16	127	132	-71	-61

Appendix 8. Data Used in the Benefits Analysis

This Appendix describes the original sources of data used to derive external costs by pollutant and country. The main reference texts are reports on the ExternE Project (European Commission, 1995, 1999) and an earlier study on the proposed incineration directive (AEA Technology and others, 1995).

Analysis of the effects of SO_2, PM_{10} and NO_x included assessment of effects on crops, buildings and health. Unlike the earlier study on the NEC and ozone Directives, effects on forests and visibility were excluded, as either being prone to too high a level of uncertainty or as being trivial (at least, according to our calculations).

1. Modelling Pollution Concentrations and Deposition

The model underlying dispersion and concentration data is the Windrose Trajectory Model (WTM) within the EcoSense framework, developed under the ExternE Project (European Commission, 1999). This has been validated against other pan-European models. The model simplifies the analysis in some respects, but overall there is little difference in results obtained for calculation of environmental benefits using the WTM and (e.g.) the EMEP model.

2 Health Effects Assessment

2.1 Stock at risk data and atmospheric modelling

Stock at risk data and atmospheric modelling were carried out using the EcoSense model developed for the ExternE Project (European Commission 1999). Ozone modelling was dealt with outside EcoSense, drawing on analysis based on the EMEP ozone model (Rabl and Eyre, in European Commission, 1999).

2.2 Exposure-response functions for primary and secondary PM_{10}, SO_2, NO_2 and ozone

The available literature on the health effects of air pollution has been reviewed by Hurley, Donnan and their colleagues at the Institute of Occupational Medicine, providing the exposure-response functions listed in Table 1. The protocol followed was to review the literature to identify effects for which the evidence seemed reasonably strong. The reported functions for these effects are taken from individual studies that appear representative of the broader literature. Table 1 contains a 'core' set of exposure-response functions. Table 2 lists functions recommended only for use in sensitivity analysis within the ExternE Project. Many different sensitivity analyses could be performed for the present study. The functions listed in Table 2 have not been included here; the Table is retained here for the purposes of transparency.

Table 1. Quantification of human health impacts. The exposure response slope, f_{er}, has units of [cases/(yr-person-ug/m^3)] for morbidity, [% change in annual mortality rate/(ug/m^3)] for acute effects on mortality, and years of life lost for chronic effects on mortality.

Receptor	Impact Category	Reference	Pollutant	f_{er} [1]
ASTHMATICS				
adults	Bronchodilator usage	Dusseldorp *et al*, 1995	PM_{10}	0.163
	Cough	Dusseldorp *et al*, 1995	PM_{10}	0.168
	Lower respiratory symptoms (wheeze)	Dusseldorp *et al*, 1995	PM_{10}	0.061
children	Bronchodilator usage	Roemer *et al*, 1993	PM_{10}	0.078
	Cough	Pope, Dockery, 1992	PM_{10}	0.133
	Lower respiratory symptoms (wheeze)	Roemer *et al*, 1993	PM_{10}	0.103
all	Asthma attacks (AA)	Whittemore, Korn, 1980	O_3	4.29E-3
ELDERLY 65 years +				
	Congestive heart failure (CHF)	Schwartz, Morris, 1995	PM_{10}	1.85E-5
CHILDREN				
	Chronic bronchitis	Dockery *et al*, 1989	PM_{10}	1.61E-3
	Chronic cough	Dockery *et al*, 1989	PM_{10}	2.07E-3
ADULTS				
	Restricted activity days (RAD)[3]	Ostro, 1987	PM_{10}	0.025
	Minor restricted activity day(MRAD)[4]	Ostro, Rothschild, 1989	O_3	9.76E-3
	Chronic bronchitis	Abbey *et al*, 1995	PM_{10}	4.9E-5
ENTIRE POPULATION				
	Respiratory hospital admissions (RHA)	Dab *et al*, 1996 Ponce de Leon, 1996	PM_{10} SO_2 O_3	2.07E-6 2.04E-6 7.09E-6
	Cerebrovascular hospital admissions (CVA)	Wordley *et al*, 1997	PM_{10}	5.04E-6
	Symptom days	Krupnick *et al*, 1990	O_3	0.033
DEATH RATES				
	Acute Mortality	WHO, 1997	PM_{10}	0.074%
	Acute Mortality	Anderson *et al*, 1996, Touloumi *et al*, 1996 Sunyer *et al*, 1996	SO_2 O_3	0.072% 0.059%
	Chronic Mortality	Pope *et al*, 1995	PM_{10}	0.00036

[1] Sources: [ExternE, European Commission, 1995b; 1998] and [Hurley and Donnan, 1997].
[3] Assume that all days in hospital for RHA, CHF and CVA are also restricted activity days (RAD). Also assume that the average stay for each is 10, 7 and 45 days respectively.

Thus, **net RAD = RAD - (RHA*10) - (CHF*7) - (CVA*45)**.

[4] Assume asthma attacks are also MRAD, and hence should deducted from the MRAD total.

Table 2. Human health functions not applied in this study, but illustrating a potential for underestimation in the benefits assessment. The exposure response slope, f_{er}, is primarily from data for Western Europe and has units of [cases/(yr-person-ug/m^3)] for morbidity, and [%change in annual mortality rate/(ug/m^3)] for mortality.

Receptor	Impact Category	Reference	Pollutant	f_{er}[1]
ELDERLY, 65 years +				
	Ischaemic heart disease	Schwartz and Morris, 1995	PM_{10}	1.75E-5
ENTIRE POPULATION				
	Respiratory hospital admissions (RHA)	Ponce de Leon, 1996	NO_2	2.34E-6
	ERV for COPD	Sunyer *et al*, 1993	PM_{10}	7.20E-6
	ERV for asthma	Schwartz, 1993 and Bates *et al*, 1990	PM_{10}	6.45E-6
		Cody *et al*, 1992 and Bates *et al*, 1990	O_3	1.32E-5
	ERV for croup in pre school children	Schwartz *et al*, 1991	PM_{10}	2.91E-5
	Acute Mortality	Sunyer *et al*, 1996, Anderson *et al*, 1996	NO_2	0.034%

[1] See footnotes to Table AII.1.

2.3 Exposure-response functions for trace pollutants

The data used for analysis of the externalities of Cd and dioxin were based on results from the earlier report on the draft incineration directive (AEA Technology and others, 1996). The ranges adopted in this study were based on alternative assumptions on survivability and development of functions:

- The high estimate was based directly on the data used in the incineration directive analysis.
- The best estimate was based on 50% of individuals contracting cancer as a consequence of exposure dying as a result, and 50% surviving after treatment
- The low estimate was taken as a factor 10 lower than the best estimate, to account for safety factors introduced in the development of the risk factors.

2.4 Valuation data

Valuation of mortality related to air pollution exposure has been conducted using both the value of statistical life (VOSL) and value of life year (VOLY) approaches. Debate on this issue is continuing. Values used are shown in Tables 3 and 4.

Valuation of the effects of PM_{10}, SO_2 and NO_x/ozone on mortality was carried out using the VOLY approach to derive best estimates. However, for the carcinogens, dioxins and cadmium, the VOSL approach was used to give best estimates. At first sight this may appear inconsistent. However, we do not believe that this is the case. It is consistent from the perspective of seeking to reflect likely differences in willingness to pay for protection of health against effects that may cause a small loss of life (in terms of the amount of life-shortening per case) in contrast to effects like cancers that are likely to lead to the loss of several or many years of life.

Table 3. Estimated VOLY for acute and chronic effects of air pollution at different discount rates. The 4% discount rate is selected as a median estimate.

Type of effect/discount rate	euro
Acute effects on mortality	
VOLY	110,000
Chronic effects on mortality	
VOLY	67,000
Other effects on mortality	
VOSL	3,200,000

Table 4. Values used for assessment of morbidity impacts (1990 euro; Markandya, in European Commission, 1999).

Endpoint	Value	Estimation Method and Comments
Acute Morbidity		
Restricted Activity Day (RAD)	63	CVM in US estimating WTP.
Symptom Day (SD) and Minor Restricted Activity Day	6.3	CVM in US estimating WTP. Account has been taken of Navrud's study.
Chest Discomfort Day or Acute Effect in Asthmatics (Wheeze)	6.3	CVM in US estimating WTP. Same value applies to children and adults.
Emergency Room Visits (ERV)	186	CVM in US estimating WTP.
Respiratory Hospital Admissions (RHA)	6,560	CVM in US estimating WTP.
Cardiovascular Hospital Admissions	6,560	As above.
Acute Asthma Attack	31	COI (adjusted to allow for difference between COI and WTP). Applies to both children and adults.
Chronic Morbidity		
Chronic Illness (VSC)	1,000,000	CVM in US estimating WTP.
Chronic Bronchitis in Adults	88,000	Rowe et al (1995).
Non fatal Cancer	375,000	US study.
Malignant Neoplasms	375,000	Valued as non-fatal cancer.
Chronic Case of Asthma	88,000	Based on treating chronic asthma as new cases of chronic bronchitis.
Cases of change in prevalence of bronchitis in children	225	Treated as cases of acute bronchitis.
Cases of change in prevalence of cough in children	188	As above.

3 Damage to Materials

3.1 Stock at risk data and other background data

The stock at risk was derived from data on building numbers and construction materials taken from building survey information. Sources of data were Kucera *et al* (1993b), Tolstoy *et al* (1990), Ecotec (1996), and Hoos *et al* (1987). For galvanised steel in structural (non-building) applications an average was derived from European Commission (1995b) and Kucera *et al* (1993b).

The exposure-response functions require data on meteorological conditions. Of these, the most important are precipitation and humidity. Data have been taken from Kucera (1994).

3.2 Dose-response functions

The main source of data for exposure response functions used here is the work conducted under the UN ECE Programme (Kucera, 1993a, 1993b, 1994). This section lists the dose-response functions used, which should be assumed to originate from the work of Kucera unless otherwise referenced. The following key applies to all equations given:

ER	=	erosion rate (um/year)
P	=	precipitation rate (m/year)
SO_2	=	sulphur dioxide concentration (ug/m^3)
O_3	=	ozone concentration (ug/m^3)
H^+	=	acidity (meq/m^2/year)
R_H	=	average relative humidity, %
f_1	=	$1-\exp[-0.121.R_H/(100-R_H)]$
TOW	=	fraction of time relative humidity exceeds 80% and temperature >0°C
ML	=	mass loss (g/m^2) after 4 years

In all the ICP functions, the original H^+ concentration term (in mg/l) has been replaced by an acidity term using the conversion:
$P \cdot H^+$ (mg/l) = $0.001 \cdot H^+$ (acidity in meq/m^2/year)

To convert mass loss for stone and zinc into an erosion rate in terms of material thickness, respective densities of 2.0 and 7.14 tonnes/m^3 are assumed. The functions used are as follows:

Unsheltered limestone (4 years): $ML = 8.6 + 1.49.TOW.SO_2 + 0.097.H^+$

Unsheltered sandstone (4 years) (also mortar): $ML = 7.3 + 1.56.TOW.SO_2 + 0.12.H^+$

Brickwork: no effect

Concrete: assumed no effect, though air pollution may affect steel reinforcement

Carbonate paint: $\Delta ER/tc = 0.01[P]8.7(10^{-pH} - 10^{-5.2})+0.006.SO_2.f_1$ (Haynie, 1986)

Silicate paint: $\Delta ER/tc = 0.01[P]1.35(10^{-pH} - 10^{-5.2})+0.00097.SO_2.f_1$ (Haynie, 1986)

Steel: assumed either painted or galvanised, not assessed independently

Unsheltered zinc (4 years): ML = $14.5 + 0.043.TOW.SO_2.O_3 + 0.08.H^+$

Sheltered zinc (4 years): ML = $5.5 + 0.013.TOW.SO_2.O_3$

Aluminium: assumed too corrosion resistant to be affected significantly.

3.3 Calculation of repair frequency

It is assumed that maintenance is ideally carried out after a given thickness of material has been lost. This parameter is set to a level beyond which basic or routine repair schemes may be insufficient, and more expensive remedial action would be needed. A summary of the critical thickness loss for maintenance and repair are shown in Table 5.

Table 5. Assumed critical thickness for maintenance or repair measures for building materials.

Material	Critical thickness loss
Natural stone	5 mm
Rendering	5 mm
Mortar	5 mm
Zinc:	
Construction - sheet and strip	25 um
Other construction, agriculture and street furniture	50 um
Pylons, other transport	100 um
Galvanised steel	50 um
Paint	20 um

3.4 Repair costs

Following from assessment of maintenance intervals, repair costs are calculated using the figures shown in Table 6.

Table 6. Repair and maintenance costs [euro / m^2] applied in this analysis.

Material	euro / m^2
Zinc	21
Galvanised steel	25
Natural stone	235
Rendering, mortar	25
Paint	11

4 Effects of Air Pollution on Agricultural Systems

4.1 Acidification of agricultural soils

Lime is routinely applied to farmland to counteract acidification linked to farming practises, including harvest. Atmospheric deposition increases the amount of lime required to maintain acidity levels. The basis of the method applied here to calculate the costs associated with this change in demand for lime is as follows:

- The total amount of acidifying pollutant deposited to the land surface in a given area;
- The amount which falls on soils which require lime (excluding, for example, urban areas, water and soils on calcareous drifts);
- The cost of neutralising this amount of acidic deposition with lime;
- The increased acidic deposition in this area resulting from the change from one scenario to another;
- The additional cost of neutralising the difference in inputs to soils, which require lime (priced at 16.8 euro per tonne of lime).

4.2 Fertilisational effects of nitrogen deposition

Nitrogen is of course an essential plant nutrient, applied by farmers in large quantity to their crops. The deposition of additional nitrogen to agricultural soils is thus beneficial (assuming that the dosage of any fertiliser applied by a farmer is not excessive). The analysis quantifies total deposition of nitrogen to arable land and permanent pastures. The benefit is calculated directly from the cost of nitrate fertiliser, 430 euro /tonne of nitrogen (Nix, 1990). Given that additional inputs will still be needed under current conditions to meet crop N requirements for intensive agricultural systems there is a negligible saving in the time required for fertiliser application (if any). Therefore it seems reasonable to cost benefits purely in terms of the (perhaps theoretical) reduction in N required as fertiliser. This analysis probably tends to overestimates the benefit of N deposition. N is deposited from the atmosphere throughout the year, including times when crops are not actively growing. The potential for deposited N to drain off and cause eutrophication is not monetised.

Similar analysis has not been performed for afforested areas. There is concern that prolonged deposition of N to these areas can lead to nutrient imbalance (Schulze *et al*, 1989), and hence that observed benefits in terms of enhanced productivity are not sustainable.

4.3 Ozone effects

Ozone damage to crops has been calculated using EMEP's accumulated ozone above a threshold of 40 ppb (AOT40) metric, where AOT40 is defined by:

$$AOT40 = \int \max(O_3 - 40, 0).dt$$

The time integral is over the growing season, which, for crops, is taken to be daylight hours in the months May-July. The metric has the units ppb.hours, or ppm.hours.

Functions are listed in Table 7.

Table 7. Ozone exposure-response functions.

Crop type	**Exposure Response Function**
	% loss per ppm.hour AOT40
Tolerant crops	0
Slightly sensitive crops	1.0
Sensitive crops	1.75
Very sensitive crops	3.57
Meat and milk products	0.5

4.4 SO_2 effects

The following functions were used to quantify % yield change (y) from SO_2 effects on agriculture, derived from the work of Baker *et al* (1986), accounting for the fertilisational effect of sulphur at low concentration (European Commission, 1995b):

$y = 0.74(SO_2) - 0.055(SO_2)^2$ (from 0 to 13.6 ppb SO_2)

$y = -0.69(SO_2) + 9.35$ (above 13.6 ppb SO_2)

These functions have been applied to the following crops:

maize	barley	wheat	sorghum
oats	rye	millet	rice
leaf crops	sugar beet	raspberries	strawberries
soybeans	beans	potato	tomato
sunflower	carrots	cucumber	flax
hops	hemp	linseed	sesame seed
tobacco			

For pasture the following function has been used, based on a review by Roberts (1984). All data used to derive the functions was taken from studies on *Lolium perenne*, the most common pasture grass in Europe. Again, the functions have been adapted to account for fertilisation of crops below the lowest exposure adopted experimentally.

$y = 0.20(SO_2) - 0.013(SO_2)^2$ (from 0 to 15.3 ppb)

$y = -0.18(SO_2) + 2.75$ (above 15.3 ppb)

Meat and milk production are assumed to be 50% as sensitive as pasture grass, on which livestock are primarily dependent for food.

4.5 Valuation of crop losses

Valuation of crop losses has been undertaken using prices from United Nations Food and Agriculture Organisation (FAO, 1994).

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Appendix 9.
Environmental valuation results

INCINERATION TO HIGH QUALITY RECYCLING

Results in € / tonne

BEST ESTIMATE	**Rigid PVC Replacement basis of MSW for PVC at incinerator**			**Flexible PVC Replacement basis of MSW for PVC at incinerator**		
Externality	**none**	**mass**	**heat**	**none**	**mass**	**heat**
Methane		-6.30	-10.19		-6.30	-12.59
CO_2	-75	-70	-67	-62	-57	-52
Dust (taken as all $PM_{10)}$	-76	-75	-74	-48	-47	-46
NO_x	-180	-170	-164	-116	-106	-96
SO_2	-145	-143	-141	-91	-89	-86
HCl						
Cd	-0.02		0.01	-0.02		0.02
Pb and other metals	-0.06	-0.03	-0.02	-0.05	-0.02	0.00
Dioxin	-0.15		0.09	-0.15		0.15
Accidents	-1.32	-4.61	-6.64	1.95	-1.34	-4.63
Electricity	84.6	76.1	70.8	87.8	79.3	70.9
Total	**-394**	**-393**	**-393**	**-227**	**-226**	**-226**
LOW ESTIMATE						
Methane		-1.29	-2.09		-1.29	-2.58
CO_2	-15	-14	-13	-12	-11	-10
Dust (taken as all $PM_{10)}$	-8	-8	-8	-5	-5	-5
NO_x	-20	-19	-18	-13	-12	-11
SO_2	-21	-20	-20	-13	-13	-12
HCl						
Cd	0.00		0.00	0.00		0.00
Pb and other metals	-0.03	-0.02	-0.01	-0.02	-0.01	0.00
Dioxin	-0.01		0.01	-0.01		0.01
Accidents	-1.32	-4.61	-6.64	1.95	-1.34	-4.63
Electricity	10.0	9.0	8.3	10.3	9.3	8.3
Total	**-55**	**-58**	**-60**	**-31**	**-34**	**-37**
HIGH ESTIMATE						
Methane		-48.00	-77.62		-48.00	-95.90
CO_2	-552	-514	-491	-455	-418	-381
Dust (taken as all $PM_{10)}$	-223	-220	-219	-140	-137	-134
NO_x	-541	-511	-492	-347	-317	-287
SO_2	-426	-419	-414	-268	-260	-252
HCl						
Cd	-0.03		0.02	-0.03		0.03
Pb and other metals	-0.09	-0.05	-0.03	-0.07	-0.03	0.01
Dioxin	-0.26		0.16	-0.26		0.26
Accidents	-1.32	-4.61	-6.64	1.95	-1.34	-4.63
Electricity	243.8	219.3	204.2	253.2	228.7	204.2
Total	**-1500**	**-1498**	**-1496**	**-955**	**-953**	**-950**

INCINERATION TO LOW QUALITY RECYCLNG

Results in € / tonne

	Rigid PVC Replacement basis of MSW for PVC at incinerator			Flexible PVC Replacement basis of MSW for PVC at incinerator		
BEST ESTIMATE						
Externality	**none**	**mass**	**heat**	**none**	**mass**	**heat**
Methane		-6.30	-10.19		-6.30	-12.59
CO_2	-40	-35	-32	-40	-35	-30
Dust (taken as all PM_{10})	-13	-12	-11	-8	-7	-6
NO_x	-28	-18	-12	-21	-11	-1
SO_2	-32	-29	-27	-20	-18	-15
HCl						
Cd	-0.02		0.01	-0.02		0.02
Pb and other metals	-0.03	0.00	0.01	-0.03	0.00	0.02
Dioxin	-0.15		0.09	-0.15		0.15
Accidents	-1.32	-4.61	-6.64	1.95	-1.34	-4.63
Electricity	61.0	52.5	47.2	64.2	55.7	47.2
Total	**-54**	**-53**	**-53**	**-24**	**-23**	**-22**
LOW ESTIMATE						
Methane		-1.29	-2.09		-1.29	-2.58
CO_2	-8	-7	-6	-8	-7	-6
Dust (taken as all PM_{10})	-1	-1	-1	-1	-1	-1
NO_x	-3	-2	-1	-2	-1	0
SO_2	-4	-4	-4	-3	-2	-2
HCl						
Cd	0.00		0.00	0.00		0.00
Pb and other metals	-0.02	0.00	0.01	-0.01	0.00	0.01
Dioxin	-0.01		0.01	-0.01		0.01
Accidents	-1.32	-4.61	-6.64	1.95	-1.34	-4.63
Electricity	7.2	6.2	5.6	7.6	6.6	5.6
Total	**-11**	**-14**	**-16**	**-5**	**-8**	**-11**
HIGH ESTIMATE						
Methane		-48.00	-77.62		-48.00	-95.90
CO_2	-295	-258	-235	-295	-258	-221
Dust (taken as all PM_{10})	-38	-35	-34	-24	-22	-19
NO_x	-85	-55	-37	-62	-32	-2
SO_2	-93	-85	-81	-60	-52	-44
HCl						
Cd	-0.03		0.02	-0.03		0.03
Pb and other metals	-0.05	-0.01	0.02	-0.04	0.00	0.03
Dioxin	-0.26		0.16	-0.26		0.26
Accidents	-1.32	-4.61	-6.64	1.95	-1.34	-4.63
Electricity	175.7	151.2	136.1	185.1	160.6	136.2
Total	**-338**	**-335**	**-334**	**-255**	**-253**	**-250**

LANDFILL TO HIGH QUALITY RECYCLING

Results in € / tonne

BEST ESTIMATE	Rigid PVC Replacement basis of MSW for PVC at incinerator			Flexible PVC Replacement basis of MSW for PVC at incinerator		
Externality	**none**	**mass**	**heat**	**none**	**mass**	**heat**
Methane						
CO_2	-35	-35	-35	-26	-26	-26
Dust (taken as all $PM_{10)}$	-63	-63	-63	-39	-39	-39
NO_x	-152	-152	-152	-94	-94	-94
SO_2	-113	-113	-113	-71	-71	-71
HCl						
Cd						
Pb and other metals	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02
Dioxin						
Accidents	4.00	4.00	4.00	4.00	4.00	4.00
Electricity	70.8	70.8	70.8	70.8	70.8	70.8
Total	**-288**	**-288**	**-288**	**-155**	**-155**	**-155**
LOW ESTIMATE						
Methane						
CO_2	-7	-7	-7	-5	-5	-5
Dust (taken as all $PM_{10)}$	-7	-7	-7	-4	-4	-4
NO_x	-17	-17	-17	-10	-10	-10
SO_2	-16	-16	-16	-10	-10	-10
HCl						
Cd						
Pb and other metals	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Dioxin						
Accidents	4.00	4.00	4.00	4.00	4.00	4.00
Electricity	8.3	8.3	8.3	8.3	8.3	8.3
Total	**-34**	**-34**	**-34**	**-18**	**-18**	**-18**
HIGH ESTIMATE						
Methane						
CO_2	-256	-256	-256	-188	-188	-188
Dust (taken as all $PM_{10)}$	-185	-185	-185	-115	-115	-115
NO_x	-457	-457	-457	-283	-283	-283
SO_2	-331	-331	-331	-208	-208	-208
HCl						
Cd						
Pb and other metals	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03
Dioxin						
Accidents	4.00	4.00	4.00	4.00	4.00	4.00
Electricity	204.2	204.2	204.2	204.2	204.2	204.2
Total	**-1020**	**-1020**	**-1020**	**-587**	**-587**	**-587**

LANDFILL TO LOW QUALITY RECYCLING

Results in € / tonne

BEST ESTIMATE	Rigid PVC Replacement basis of MSW for PVC at incinerator			Flexible PVC Replacement basis of MSW for PVC at incinerator		
Externality	**none**	**mass**	**heat**	**none**	**mass**	**heat**
Methane						
CO_2	0.127	0.127	0.127	-3.796	-3.796	-3.796
Dust (taken as all PM_{10})	0.058	0.058	0.058	0.058	0.058	0.058
NO_x	-0.494	-0.494	-0.494	0.367	0.367	0.367
SO_2	0.811	0.811	0.811	0.019	0.019	0.019
HCl						
Cd						
Pb and other metals						
Dioxin						
Accidents	4	4	4	4	4	4
Electricity	47	47	47	47	47	47
Total	**52**	**52**	**52**	**48**	**48**	**48**
LOW ESTIMATE						
Methane						
CO_2	0	0	0	-1	-1	-1
Dust (taken as all PM_{10})	0	0	0	0	0	0
NO_x	0	0	0	0	0	0
SO_2	0	0	0	0	0	0
HCl						
Cd						
Pb and other metals						
Dioxin						
Accidents	4.00	4.00	4.00	4.00	4.00	4.00
Electricity	5.6	5.6	5.6	5.6	5.6	5.6
Total	**10**	**10**	**10**	**9**	**9**	**9**
HIGH ESTIMATE						
Methane						
CO_2	1	1	1	-28	-28	-28
Dust (taken as all PM_{10})	0	0	0	0	0	0
NO_x	-1	-1	-1	1	1	1
SO_2	2	2	2	0	0	0
HCl						
Cd						
Pb and other metals						
Dioxin						
Accidents	4.00	4.00	4.00	4.00	4.00	4.00
Electricity	136.1	136.1	136.1	136.1	136.1	136.1
Total	**142**	**142**	**142**	**114**	**114**	**114**

INCINERATION TO LANDFILL

Results in € / tonne

BEST ESTIMATE	Rigid PVC Replacement basis of MSW for PVC at incinerator			Flexible PVC Replacement basis of MSW for PVC at incinerator		
Externality	**none**	**mass**	**heat**	**none**	**mass**	**heat**
Methane		-6.30	-10.19		-6.30	-12.59
CO_2	-40	-35	-32	-37	-31	-26
Dust (taken as all $PM_{10)}$	-13	-12	-11	-8	-7	-7
NO_x	-28	-18	-12	-21	-11	-1
SO_2	-33	-30	-28	-20	-18	-15
HCl						
Cd	-0.02		0.01	-0.02		0.02
Pb and other metals	-0.03	0.00	0.01	-0.03	0.00	0.02
Dioxin	-0.15		0.09	-0.15		0.15
Accidents	-5.32	-8.61	-10.64	-2.05	-5.34	-8.63
Electricity	13.7	5.2		17.0	8.5	0.0
Total	**-106**	**-105**	**-104**	**-72**	**-71**	**-70**
LOW ESTIMATE						
Methane		-1.29	-2.09		-1.29	-2.58
CO_2	-8	-7	-6	-7	-6	-5
Dust (taken as all $PM_{10)}$	-1	-1	-1	-1	-1	-1
NO_x	-3	-2	-1	-2	-1	0
SO_2	-5	-4	-4	-3	-3	-2
HCl						
Cd	0.00		0.00	0.00		0.00
Pb and other metals	-0.02	0.00	0.01	-0.01	0.00	0.01
Dioxin	-0.01		0.01	-0.01		0.01
Accidents	-5.32	-8.61	-10.64	-2.05	-5.34	-8.63
Electricity	1.6	0.6		2.0	1.0	0.0
Total	**-21**	**-24**	**-26**	**-14**	**-16**	**-19**
HIGH ESTIMATE						
Methane		-48.00	-77.62		-48.00	-95.90
CO_2	-296	-259	-236	-268	-230	-193
Dust (taken as all $PM_{10)}$	-38	-36	-34	-25	-22	-19
NO_x	-84	-54	-35	-63	-33	-3
SO_2	-96	-88	-83	-60	-52	-44
HCl						
Cd	-0.03		0.02	-0.03		0.03
Pb and other metals	-0.05	-0.01	0.02	-0.04	0.00	0.03
Dioxin	-0.26		0.16	-0.26		0.26
Accidents	-5.32	-8.61	-10.64	-2.05	-5.34	-8.63
Electricity	39.6	15.1		49.0	24.5	0.0
Total	**-480**	**-477**	**-476**	**-369**	**-366**	**-364**

ENVIRONMENTAL COSTS OF THE SCENARIOS

The results of the environmental analysis were relatively insensitive to whether the scenarios were examined under the high or low incineration futures,.as illustrated in Table 18. Therefore to improve clarity, subsequent results for the environmental analysis have been based on the mean of the high and low incineration futures, shown in the shaded cells of Table 18.

Table 18: Overall environmental costs of the scenarios, rigid and flexible PVC (not discounted).

Externality valuation	Scenario 1 Incineration future			Scenario 2 Incineration future			Scenario 3 Incineration future		
	High	Low	Mean	High	Low	Mean	High	Low	Mean
Low	-187	-182	-184	-309	-298	-304	-213	-185	-199
Best estimate	-1409	-1385	-1397	-2315	-2266	-2291	-935	-809	-872
High	-5206	-5097	-5152	-8809	-8580	-8695	-4544	-3932	-4238

The following tables show the total quantified environmental costs for each of the scenarios, based on the valuations for each diversion route given above and the amounts of PVC waste following each route, as given in Table 7 of the main report.

Table 19: Overall environmental costs of the scenarios, million € 2000-2020, rigid PVC.

0% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-171	-264	-97
Best estimate	-1296	-1987	-433
High	-4749	-7316	-1967
Low	-9	-13	-5
Best estimate	-65	-99	-22
High	-237	-366	-98

2% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-132	-204	-75
Best estimate	-1002	-1536	-334
High	-3671	-5656	-1520
Annualised costs, million Euro/year			
Low	-8	-12	-5
Best estimate	-61	-94	-20
High	-225	-346	-93

4% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-104	-160	-59
Best estimate	-786	-1205	-262
High	-2879	-4436	-1192
Annualised costs, million Euro/year			
Low	-8	-12	-4
Best estimate	-58	-89	-19
High	-212	-326	-88

6% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-83	-127	-47
Best estimate	-625	-958	-209
High	-2289	-3527	-948
Annualised costs, million Euro/year			
Low	-7	-11	-4
Best estimate	-54	-84	-18
High	-200	-308	-83

Table 20: Overall environmental costs of the scenarios, million € 2000-2020, <u>flexible</u> PVC.

0% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-13	-40	-102
Best estimate	-101	-304	-440
High	-403	-1378	-2271
Low	-1	-2	-5
Best estimate	-5	-15	-22
High	-20	-69	-114

2% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-10	-31	-79
Best estimate	-78	-235	-340
High	-312	-1065	-1756
Annualised costs, million Euro/year			
Low	-1	-2	-5
Best estimate	-5	-14	-21
High	-19	-65	-107

4% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-8	-24	-62
Best estimate	-61	-184	-266
High	-244	-836	-1377
Annualised costs, million Euro/year			
Low	-1	-2	-5
Best estimate	-5	-14	-20
High	-18	-61	-101

6% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-6	-19	-49
Best estimate	-49	-146	-212
High	-194	-664	-1095
Annualised costs, million Euro/year			
Low	-1	-2	-4
Best estimate	-4	-13	-18
High	-17	-58	-95

Table 21: Overall environmental costs of the scenarios, million € 2000-2020, rigid + flexible PVC.

0% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-184	-304	-199
Best estimate	-1397	-2291	-872
High	-5152	-8695	-4238
Low	-9	-15	-10
Best estimate	-70	-115	-44
High	-258	-435	-212

2% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-143	-235	-154
Best estimate	-1080	-1771	-674
High	-3983	-6722	-3276
Annualised costs, million Euro/year			
Low	-9	-14	-9
Best estimate	-66	-108	-41
High	-244	-411	-200

4% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-112	-184	-121
Best estimate	-847	-1389	-529
High	-3123	-5271	-2569
Annualised costs, million Euro/year			
Low	-8	-14	-9
Best estimate	-62	-102	-39
High	-230	-388	-189

6% discount rate	**Scenario 1**	**Scenario 2**	**Scenario 3**
Total cost, million Euro			
Low	-89	-146	-96
Best estimate	-674	-1104	-420
High	-2484	-4192	-2043
Annualised costs, million Euro/year			
Low	-8	-13	-8
Best estimate	-59	-96	-37
High	-217	-365	-178