The Future of Biodegradable Waste Management in the UK

A thesis submitted to Imperial College London for the degree of Doctor of Philosophy

By

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2010

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Declaration of Originality

I declare that this thesis, *The Future of Biodegradable Waste Management* in the UK, is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced and with appropriate acknowledgement given

Abstract

The WRATE LCA model was used to compare the environmental impacts of incineration and MBT to landfilling residual household waste, using The London Borough of Barnet as a case study. Incineration performed best, followed by MBT processes that produced fuel. MBT that produced stabilised material for landfill showed little advantage over landfilling directly. The applicability of the internationally obtained WRATE dataset to the UK was assessed by analysing samples of UK MBT outputs for biological content. These results were used in GasSim to produce long-term gas emission profiles from a landfill. Total gas emissions were reduced, but the timescale of emissions was similar to untreated waste presenting a challenge to landfill management. The WRATE model assumes products resulting from MBT will be used for their intended purpose, however, an assessment of the potential UK market was lacking. Interviews with representatives from relevant industries and a literature review were conducted to fill this data gap. It was found that approximately half of the biodegradable household waste produced annually could be used as SRF, depending on reliability, and competition with other renewable fuels. The use of MBT outputs as a soil conditioner is less likely in the current regulatory framework, however, ongoing trials may prove that it's safe to use, significantly increasing the potential market. GHG emissions from application to land, which has been overlooked in previous research, was addressed using UK samples. A common flux chamber technique was successfully adapted for this new purpose. The dependence of the perceived environmental benefit of incineration and SRF use on the fuels used to generate electricity was modelled and found to be significant, especially for incineration, which in one case had a similar impact to landfilling. Limitations to using LCA for waste management decision-making are discussed and alternative approaches considered. Opportunities for prevention of biodegradable wastes are considered significant.

Table of Contents

Acknowledgements 12

Publications 13

1. Introduction 14

2. Aims and Objectives 33

3. Life-cycle assessment comparison of biological waste treatment methods using WRATE 35

3.1. Introduction 35

3.2. Description of WRATE 37

3.3. Method 43

3.4. Impact assessment and interpretation 50

3.5. Conclusion and suggestions for future work 61

4. Varying the electricity mix 62

4.1. Introduction 62

4.2. LCA of energy 64

4.3. Methodology 68

4.4. Results and discussion 69

4.5. Conclusions 79

5. Characterization of CLOs from biologically pretreated BMW 82

5.1. Introduction 82

5.2. Materials and methodology 83

5.2.1. Sampling method 83

5.2.2. Description of Samples 83
5.3. Analytical procedure 85
5.4. Results 86
5.4.1. Visual inspection 86
5.4.2. Moisture, cellulose, hemicellulose and lignin content 87
5.5. Discussion 88
5.6. Conclusions 93
6. Modelling gas emissions from landfills accepting CLOs 94
6.1. Introduction 94
6.2. Modelling landfill gas emissions with GasSim 96
6.3. GasSim modelling methodology 99
6.4. Results 100
6.5. Discussion 104
6.6. Comparing GasSim and LCA results 107
7. Marketability of MBT outputs: SRF and CLOs 109
7.1. Introduction 109
7.2. Regulation of SRF use 110
7.3. Current and planned SRF production and use in the UK 112
7.4. Marketability of compost from mixed residual waste 123
8. Application of CLOs to land 125
8.1. Introduction 125
8.2. Methodology 127

8.2.1. Flux chambers 130
8.3. Results 134
8.4. Discussion 138
8.5. Conclusions and future recommendations 140
9. Limitations of Applying LCA to waste management 141
9.1. Introduction 141
9.2. Methodology 144
9.3. Results 145
9.4. Discussion 155
10. Conclusions and suggestions for future work 163
References 168
Appendices 181

List of Tables

Table 1: MSW waste composition in England (Resource Futures, 2009) 20
Table 2: Overview of MBT and MHT sites in the UK (Burgess, 2010) 26
Table 3: Waste composition for London Borough of Barnet case study (Resource Futures, 2009) 45
Table 4: Assumed percentage of recyclables in residual waste stream 46
Table 5: Description of MBT processes (Environment Agency, 2007) 49
Table 6: Outputs from MBT processes 50
Table 7: Electricity mix data for Norway, France, Lithuania and the UK (Environment Agency, 2007) 68
Table 8: Outputs from MBT processes 69

Table 9: Acidification pollutants from incineration 77

Table 10: difference in impacts with lower efficiency incineration 78

Table 11: Cellulose, hemicellulose and lignin concentration of individual waste components in percentage of dry weight (Palmisano and Barlaz, 1996) 87

Table 12: Measured mean and standard deviation of biological characteristics for all four facilities 88

Table 13: Mean biological content by % dry weight 88

Table 14: Moisture, cellulose and lignin contents (Dimambro et al., 2007) 91

Table 15: Biological treatment processes 99

Table 16: Waste Streams 100

Table 17: Mean measured percentage moisture, cellulose and hemicellulose content and standard deviation 101

Table 18: Methane reduction compared to the composition data given in the waste strategy for England 2007 and also lifetime of landfill gas passively venting 103

Table 19: CO_2 equivalents from the landfills accepting CLOs analysed in Chapter 5 108

Table 20: Sample properties (provided by suppliers) 128

Table 21: Number of samples collected at each site and time 131

Table 22: Common limitations of waste management life cycle assessment tools 142

Table 23: MBT product outputs 181

Table 24: MBT reject outputs 181

Table 25: GHG emissions by substance (kg CO_2 equivalents) 183

Table 26: Abiotic resource depletion by substance (kg antimony equivalents) 184

Table 27: Acidification impacts by pollutant (kg SO_2 equivalent) 188

Table 28: Eutrophication impacts by pollutant (kg PO_4 equivalent) 188

Table 29: Human Toxicity impacts by pollutant (kg 1,4-DCB equivalents) 189

Table 30: Freshwater ecotoxicity impacts by pollutant (kg 1,4-DCB equivalents).....194

Table 31: Pollutant emissions limits for the WID and LCPD (Faria, 2010).....199

Table 32: Summary of SRF plants currently operating in the UK.....200

Table 33: Summary of planned SRF plants in the UK that will be operational in the near future.....201

Table 34: Norway GHG emissions by pollutant (kg CO_2 equivalent).....203

Table 35: Norway abiotic resource depletion impacts by pollutant.....204

Table 36: Norway acidification impacts by pollutant (kg SO_2 equivalent) 208

Table 37: Human toxicity impacts by pollutant (kg 1,4-DCB equivalents) 209

Table 38: Norway freshwater ecotoxicity impacts by pollutant (kg 1,4-DCB equivalents) 212

Table 39: France GHG emissions impacts by pollutant (kg CO_2 equivalent) 217

Table 40: France abiotic resource depletion by pollutant (kg antimony equivalents) 219

Table 41: France acidification impacts by pollutant (kg SO_2 equivalent) 222

Table 42: France eutrophication impacts by pollutant (kg PO_4 equivalents).....223

Table 43: France human toxicity impacts by pollutant (kg 1,4-DCB equivalent).....223

Table 44: France freshwater ecotoxicity impacts (kg 1,4-DCB equivalents) 228

Table 45: Lithuania GHG emissions by pollutant (kg CO_2 equivalent) 233

Table 46: Lithuania abiotic resource depletion by pollutant (kg antimony equivalents)..234

Table 47: Lithuania acidification impacts by pollutant (kg SO_2 equivalent).....237

Table 48: Lithuania eutrophication impacts by pollutant (kg PO_4 equivalent).....237

Table 49: Lithuania human toxicity impacts by pollutant (kg 1,4-DCB equivalents) 238

Table 50: Lithuania freshwater ecotoxicity impacts by pollutant (kg 1,4-DCB equivalents) 242

Table of Figures

Figure 1: BMW landfilled in the UK with predictions to 2020 (Defra, 2008a) 15

Figure 2: Possible MBT processing options 26

Figure 3: Waste management process diagram for residuals to landfill scenario 47

Figure 4: Waste management process diagram of residuals to incineration 48

Figure 5: Greenhouse gas emission impacts by process 51

Figure 6: Abiotic resource depletion impacts by process 54

Figure 7: Human toxicity impacts by process 55

Figure 8: Freshwater ecotoxicity impacts by process 57

Figure 9: Acidification impacts by process 58

Figure 10: Eutrophication impacts by process 59

Figure 11: Normalised impacts from all scenarios 61

Figure 12: Comparison of impacts with Norwegian electricity mix 72

Figure 13: Percentage change in impacts with a French electricity mix 74

Figure 14: Lithuanian electricity mix 76

Figure 15: Normalised impacts with different electricity mixes 78

Figure 16: Stages of waste degradation in anaerobic landfill (Department of the Environment, 1995) 95

Figure 17: Gas emissions from landfills accepting half CLOs – half raw waste 102

Figure 18: Gas emissions from landfills accepting CLOs only 102

Figure 19: Gas emissions below 100 m^3/hr from landfill accepting half CLOs – half raw waste 104

Figure 20: Gas emissions below 100 m^3/hr from landfill accepting CLOs 104

Figure 21: MBT output sample 128

Figure 22: Compost sample from West London 129

Figure 23: Sewage sludge sample 130

Figure 24: Flux chamber apparatus 130

Figure 25: Map of three testing sites at Silwood Park 132

Figure 26: Picture of site 1. Samples were collected near the bottom right hand corner of the photo 133

Figure 27: Site 2 134

Figure 28: Site 3 134

Figure 29: Measured nitrogen concentrations. Solid line indicates the mean, dashed line 3 standard deviations from the mean. 136

Figure 30: Oxygen concentrations measured at each site. The solid line indicates mean ambient concentration measured, and the dashed lines are 3 standard deviations from this. 136

Figure 31: Measured CO_2 concentrations 137

Figure 32: Modelled greenhouse gas emissions ($kgCO_2$ equivalent) 147

Figure 33: GHG emissions corrected to account for emissions attributed to the water industry 148

Figure 34: Modelled acidification impacts ($kgSO_2$ equivalent) 149

Figure 35: Modelled eutrophication impacts ($kgPO_4$ equivalents) 149

Figure 36: Modelled freshwater ecotoxicity impacts (kg 1,4-DCB - equivalents) 150

Figure 37: Modelled human toxicity impacts (kg 1,4-DCB equivalents).....151

Figure 38: Modelled abiotic resource depletion impacts (kg antimony equivalent).....152

Figure 39: Home-composting case impacts 154

Acknowledgements

I would like to thank my supervisors Nikolaos Voulvoulis and Jan Gronow for their support and guidance throughout my project and for giving me opportunities to present and publish my research.

I would also like to acknowledge the wonderful support of Carmelina Vinci, Anna Lisowska and Isabelle Hanlon with all my administration processes.

I would like to acknowledge Thomas Bateson, who assisted with the analysis of the MBT CLOs as part of his MSc research project; Marianna Skartsila assisted with the application to land experiment as part of her MSc research project; and Amar Lochab for work on the SRF.

I would also like to thank Professor Kevin Clemitshaw and Ute Skiba from the Centre for Ecology and Hydrology for providing invaluable guidance on the flux chamber experimental set up; Jim Frederickson and Graham Howell from the Open University for supplying the MBT CLO samples; Becky Arnold for the digestate samples and for her information regarding the South Shropshire biowaste digester; Ben Donaldson from London Waste Eco Park for giving us a tour of the composting site, and allowing us to take samples; Guy Ohandja for arranging digested sewage sludge samples; Mick Crawley and everyone at Silwood Park for providing us with space to perform the application to land experiments, and assisting with the field work.

I would also like to thank Keith Knox, Richard Murphy, Nigel Bell, for providing guidance and support during my research.

And finally everyone in room 310 over the years for your friendship and support.

Publications

S. Donovan, J. Gronow and N. Voulvoulis (2008). The global warming potential of biodegradable municipal waste management options. Proceedings Waste 2008: Waste and Resource Management – a shared responsibility, Stratford-upon-Avon, Warwickshire, England. 16-17 September 2008. (An early version of Chapter 1)

S. Donovan, T. Bateson, J. Gronow and N. Voulvoulis (2009). Modeling the greenhouse gas emissions of biologically pretreated waste in landfill. Proceedings XII International Waste Management and Landfill Symposium. Cagliari, Sardinia 5-9th October, 2009. (A combination of Chapters 5 and 6)

S. Donovan, T. Bateson, J. Gronow and N. Voulvoulis (2010). Characterisation of Compost-Like-Outputs from Mechanical Biological Treatment of Municipal Solid Waste. Journal of the air and waste management 60(6): 694-701. (Based on Chapter 5)

S. M. Donovan, T. Bateson, J. R. Gronow and N. Voulvoulis (2010). Modelling the Behaviour of Mechanical Biological Treatment outputs in landfills using the GasSim model. Science of the total environment 408(8): 1979-1984. (Based on Chapter 6)

S. M. Donovan, J. Pan, T. Bateson, J. R. Gronow and N. Voulvoulis (2010). Gas Emissions from Biodegradable waste in Landfill. From Sanitary to Sustainable Landfill – why, how and when? 1st International conference on final sinks, 23rd-25th September, Vienna. (Based on Chapters 5 and 6, in combination with the work of Tom Bateson and Jilang Pan, so show how the department has contributed to this area over time)

S. M. Donovan, J. Pan, T. Bateson, J. R. Gronow and N. Voulvoulis (2011). Gas emissions from biodegradable waste in United Kingdom landfills. Waste management and research 29(1): 69-76. (The conference paper upgraded for inclusion in the journal after the conference)

S. M. Donovan, A. M. Skartsila, M. K. Head and N. Voulvoulis (2011). An initial investigation into the use of a flux chamber technique to measure soil atmosphere gas exchanges from the application of biosolids to UK soils. Applied and Environmental Soil Science. (In press) (Based on Chapter 8)

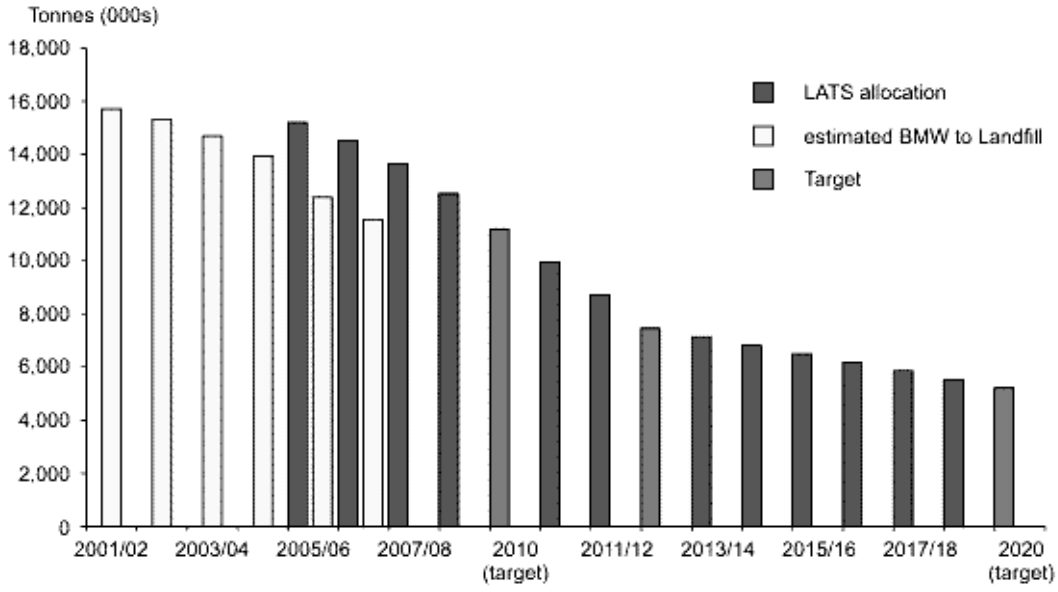
1. Introduction

Landfilling of biodegradable solids can lead to many environmental problems due to the gas produced during biodegradation under these anaerobic conditions. They include fires and explosions, odour nuisance, local air quality pollution, effects on vegetation and human health, and greenhouse gas emissions. Finding other methods of treating this waste is therefore considered an appropriate strategy for reducing potential environmental harm. The European Union has thus made diversion of biodegradable municipal solid waste a statutory obligation in article 5 paragraph 2 of the Directive on the landfilling of waste (99/31/EC) (Council of the European Union, 1999). The directive contains three target dates for the reduction of the mass of biodegradable municipal waste to landfill compared to 1995 levels, by 75% in 2006, 50% in 2009 and 35% in 2016. However, countries which landfilled more than 80% of their biodegradable municipal waste (BMW) at the time the directive was released were granted a four year derogation, including the UK, pushing the target dates to 2010, 2013 and 2020.

The European directive on waste, known as the waste framework directive (Parliament & Council of the European Union, 2008) defines waste as 'any substance or object which the holder discards or intends to or is required to discard.' It does not have a separate definition of municipal solid waste, allowing member states to set their own. In the UK it was defined as any waste collected by or on behalf of a local authority, comprising mostly household waste, but may include some commercial and industrial wastes of similar composition (Defra, 2010d) however in 2010 the government redefined municipal waste, to bring it into line with the rest of Europe, as household waste and commercial and industrial waste of similar composition, even where it is collected by private operators. As most of the work conducted in this thesis took place prior to the new definition, the assessments are related to the old definition.

To enforce the biodegradable waste diversion targets in the UK the government introduced landfill allowance trading schemes (LATS) in April, 2005 in Scotland, England and Northern Ireland, and in October 2004 in Wales. Under the scheme waste disposal authorities (WDA) were allocated a weight based allowance for annual deposition of BMW in landfill. The allowances were based on mass landfilled in 2001/02 being reduced incrementally each year

until the target year, the masses are shown in Figure 1. In England and Scotland WDAs are allowed to trade, i.e. buy or sell allowances with other authorities; bank, i.e. set aside unused allowances to use up in a later year; or borrow, i.e. use up to 5% of their following years quota in a given year, if they are confident they will not need it later. In Wales and Northern Ireland allowances are not tradable, but in Northern Ireland unused allowances are permitted to be transferred between authorities. A WDA will be fined £150 per tonne for any excess BMW landfilled except in Northern Ireland where the fine is £200 per tonne. If allowed weights are exceeded in a directive target year then some or all of the EU fines can be passed on to responsible authorities (Defra, 2005a). Defra reports that in 2007/08 10.6 Mt of BMW were landfilled compared to 11.5 Mt in 2006/07 and 13.9 Mt in 2004/05. The scheme has thus been successful in motivating authorities into action, and the first target has already been exceeded. However, because the majority of councils have managed to exceed their targets, the sale of excess allowances has been less profitable than expected, with many councils only selling for £5 per tonne or less, when they were expecting to sell for £70 (Lets Recycle, 2007). There is a risk that the incentive to exceed targets so that excess credits can be sold to other authorities generating profit, will fail in England and Scotland and LATS may need to be replaced with a new regulatory instrument to ensure the later targets are achieved.



Notes: 2001/2 is the baseline allocation.
2002/3 to 2004/5 are Defra estimates based on local authority returns to the Municipal Waste Management Survey.
2005/6 is the out-turn figure calculated by the Environment Agency.

Figure 1: BMW landfilled in the UK with predictions to 2020 (Defra, 2008a)

Waste Data Flow

In order to collate waste management data, including the landfilling of BMW, the web-based system Waste Data Flow (WDF) was introduced in England in April 2004 (Environment Agency, 2010b). This simplifies the process of reporting waste data for authorities while allowing government easy access to waste statistics, in order to monitor progress towards achieving targets, such as BMW diversion from landfill. Once the data has been reported it goes through a two stage auditing process, firstly by SKM Enviros on behalf of the Environment Agency and Department for Environment, Food and Rural Affairs (Defra). This stage aims to maintain consistency across all authorities and to resolve any errors in the reporting before the data reaches the Environment Agency. The second stage is carried out by the Environment Agency and focuses on where waste has been sent for reprocessing or recovery, to ensure it has been legitimately recycled. Reports have been produced from the data for each scheme year so far. In the 2009/10 report (Environment Agency, 2010b) the Environment Agency highlights a number of common issues they have encountered while carrying out stage 2 of the auditing process. This includes not reporting accurate end destinations, 0% reject rates reported for material recovery facilities and incorrect reporting of waste data from residual waste treatment facilities. Some authorities appear to believe it is up to the contractors to track and report the final destination of the waste. This is a cause for concern relating to the BMW diversion targets as rejected BMW could be being landfilled elsewhere, and thus not compliant with the directive.

In order to assist WDAs to decide on the most appropriate waste management system for their area, the Waste Strategy for England (Defra, 2007b) has adapted the waste hierarchy from the European Waste Framework directive (Parliament & Council of the European Union, 2008) which lists treatment processes in order of preference after prevention, as reuse, recycling, recovery and landfilling. Recovery is defined as ‘any operation the principal result of which is waste serving a useful purpose’, but is most commonly interpreted as recovery for energy. However, it is made clear that the hierarchy is a guide and should be overruled where life cycle analyses indicate the preference order is not the most environmentally beneficial. Therefore life cycle assessment tools are a popular method for aiding decision making.

Environmental life cycle assessment (LCA) is “a systematic tool used for assessing the environmental impacts associated with a specific product or service” (Ciambrone, 1997).

These commonly consider the ‘cradle to grave’ of a given product, measuring and assessing the impacts of all materials, activities and energy use at each product life stage. There is an international standard (ISO 14040-14044) (British Standards Institute, 2006) methodology for performing an LCA. This consists of four stages: goal definition and scoping, inventory analysis, impact assessment and interpretation.

Goal definition sets out the precise reason for carrying out the assessment, as well as the objectives and intended audience. The scoping sets the system boundary, namely which life stages and their components that are to be included. The scoping should produce a conceptual model defining the relevant time and spatial boundaries, the operations and product life cycle stages to be included, and the types of material and energy inputs and outputs. Of critical importance at this stage is the definition of the functional unit. This unit is the number or amount of a product or service being assessed. All data collected must relate to this quantity.

Inventory analysis involves gathering all the data relevant to the components of the life stages defined during the scoping stage and listing them in an ecoinventory. This usually requires at least energy inputs, emissions of pollutants to air, water and land, and generated waste. LCA software packages often come with access to databases containing data for common processes. However, it is important that any project-specific factors that could influence the final results, such as geographical location are considered before using this generic data. Any project-specific data must be obtained through experimentation, surveys or literature searches. The data must be put into common units, and quantities must relate to the functional unit.

The impact assessment stage aims to ‘*evaluate and clarify the magnitude and significance of the potential environmental impacts’* (Clift, 2001). The ISO methodology dictates the selection of a reasonable number of impact categories which define resources use and environmental impact. The most commonly used impact categories are: abiotic resource depletion, greenhouse gas (GHG) emissions, stratospheric ozone depletion, human toxicity, aquatic or terrestrial ecotoxicity, acidification, eutrophication and photochemical oxidant creation. The items listed in the inventory are classified according to the impact category or categories to which they contribute. A single numerical value is derived for each impact category by aggregating all the relevant contributions from the inventory. The units of each category are usually defined for comparison with reference values e.g. global warming

potential is calculated as kg CO_2 equivalent. In assessing values of impact magnitude, a 10% difference in values of energy use or post consumer solid waste between systems can be considered as significant; for values of the weight of industrial solid waste, atmospheric emissions or waterborne emissions of a system, a 25% significance threshold may be appropriate (Franklin Associates, 2006). It is also possible to apply normalisation or weighting factors if desired. Normalisation factors can help relate impact category results to reference values. Weighting factors alter the impact category results in terms of their relative importance, which can allow for different impact categories to be considered as a single score.

The interpretation of the results is the final stage which allows overall conclusions to be reached. The results are evaluated for accuracy and robustness, to check that they meet the original goal and to determine conformity with the original scope and methods set for the study. The strengths, limitations and assumptions are assessed and the latter may be tested by some form of sensitivity analysis i.e. checking the extent of change in estimated impacts resulting from systematically changing key assumptions or life cycle inventory (LCI) values.

The application of LCA to waste management processes has been assessed by various studies. The Waste and Resources Action Programme (WRAP), a not for profit organisation backed by the UK Government, commissioned an international review of LCA style studies that evaluated the impact of managing materials by recycling, incineration or landfill (Denmark, 2006). WRAP found the studies consistently concluded that recycling offered more environmental benefits and lower environmental impacts, than other waste management options. It is important to note, however that the review identified a number of significant gaps within the literature and indicated that more attention should be given to boundary conditions and system assumptions in future.

A Defra study on the impact of energy from waste and recycling policy on UK GHG emissions has been carried out with the aim of updating quantitative assessments of the implications of waste management policies for UK emissions of GHGs (Fisher, 2006). A standard waste management system was adopted that assumed all separately collected dry recyclables were source-separated and passed via a clean materials recovery facility/bulking point prior to recycling/reprocessing. All other residual wastes, and wastes designated for composting, were deemed to have passed through a transfer station before reaching the

treatment facility. Although not representative of all the waste collection and management systems employed in the UK, this generic system was considered sufficiently typical and was used to provide consistent modelling between the various scenarios studied. The results showed that greenhouse gas emission profiles for the UK were dominated by the offset benefits attributed to materials recycling and, to a lesser extent, by energy recovery. The author noted that any contamination associated with separated materials and efficiencies in processing and conversion would affect both estimates of GHG emissions and the financial costs of systems employed to treat them. Scenarios developed for municipal solid waste (MSW) that incorporated higher levels of both recycling and energy recovery showed greater net GHG benefits. Key factors associated with the sensitivity of the results from the study as a whole were identified as; assumptions about waste growth and composition; choices made as to the modelled marginal electricity mix (a point raised in the WRAP study); and the position of recycling offset benefits within UK/non-UK system boundaries. Results from this study relating to specific waste types will be discussed in more detail below.

LCA tools are very complex and require a certain level of expertise to be used effectively. However, hiring an LCA expert is expensive and in the current economic situation in the UK, it will be difficult for WDAs to find funds to hire consultants to perform the analysis. The Environment Agency (for England and Wales) has attempted to improve this situation by developing a user friendly LCA tool for waste management called 'The Waste and Resources Action Tool for the Environment' (WRATE). This already has a lot of the inventory data compiled; only requiring the user to input details about their local area. Scenarios of different waste treatment systems are developed by simply dragging and dropping icons of the processes they wish to assess. Restrictions are placed on many of the processes so only appropriate wastes are allowed to enter. The model will not run unless processes are complete, i.e. all wastes are either recycled, reprocessed or landfilled.

In Chapter 3 of this thesis WRATE is used to compare twelve waste management systems for MSW, using the London Borough of Barnet as a case study to provide the input data. The discussion emphasises the fate of the biodegradable content, as the diversion of this from landfill is currently the most pressing challenge for WDAs. The typical composition of the English waste stream has been assessed on behalf of Defra (Resource Futures, 2009). Biodegradable waste was found to make up around three quarters of the UK municipal solid

waste stream. The three main types are paper/card (23%), food waste (18%) and garden waste (14%) see Table 1.

Table 1: MSW waste composition in England (Resource Futures, 2009)

England 2006/07	All municipal waste	Estimated composition all municipal waste (%)
Food	*5,056,259*	*17.84%*
Garden	*3,989,782*	*14.08%*
Other organic	*490,352*	*1.73%*
Paper	*4,718,113*	*16.65%*
Card	1,711,499	6.04%
Glass	1,881,799	6.64%
Metals	1,217,335	4.30%
Plastics	2,831,585	9.99%
Textiles	802,816	2.83%
Wood	*1,056,748*	*3.73%*
WEEE	620,566	2.19%
Hazardous	149,396	0.53%
Sanitary	712,015	2.51%
Furniture	379,783	1.34%
Mattresses	72,162	0.25%
Misc combustible	671,666	2.37%
Misc non-combustible	798,836	2.82%
Soil	52,144	0.18%
Other	658,130	2.32%
Fines	469,127	1.66%
TOTAL	28,340,112	100%

Waste fractions in italics are assumed 100% biodegradable; waste fractions in blue are assumed 50% biodegradable.

Paper and card

Paper/card is not only the largest fraction but has also been shown to make the greatest contribution to gas generation in a landfill over the long term. Pan and Voulvoulis (2007) for example, used the Environment Agency (England and Wales) GasSim model (version 1.03) to predict the contribution to methane of each fraction of the waste stream over 100 years and found paper/card made the most significant contribution from about 14 years after the landfill started. Thus its diversion from landfill is important for reducing remediation time. The slow degradation of this fraction makes is unsuitable for biological treatments such as composting, but the low moisture and high carbon content, makes it highly suited to thermal treatments. Energy generated from incineration has the advantage of offsetting the use of other fuels,

which can have environmental benefit where the electricity supply is largely fossil fuel based. If separated from the rest of the waste stream many types of paper and card can be recycled, offsetting the energy used in producing virgin paper, however, the recycling process reduces the quality of the fibres, so the number of times this can be done is limited.

The Defra report (Fisher et al., 2006) found that recycling and energy recovery through incineration of paper/card both show significant GHG savings over landfilling. On average recovery showed a greater reduction in emissions than recycling, however, the difference depended on energy conversion efficiency, which needs to be at least 50%, and the type of fuel normally used for electricity generation that incineration is replacing.

Most WDAs already offer source-segregated collection for paper/card and currently over 60% is collected for recycling (WRAP, 2007). The difficulty is that the UK paper industry relies heavily on imported goods and it is only possible to remanufacture about 45% of that collected, in the UK, the rest being exported overseas. Voluntary agreements between the government and paper industry to increase the recycled content of paper products exist (Defra, 2003), but predicted future trends indicate paper manufacturing will continue to decline in the UK, increasing the amount to be exported. Concerns over the economic stability of this situation have been raised (WRAP, 2007).

Garden and food waste

Garden and food wastes have been shown to make the most significant contribution to gas generation in landfills during the early stages of the landfill life, usually up to about 14 years (Pan and Voulvoulis, 2007). The fast degrading nature of these wastes makes them very suited to composting and this traditional method of reusing garden and food waste to return nutrients to the soil is a well established process with relatively good public perception. Home composters are encouraged by some local authorities as it removes these problematic waste streams saving costs of collection and treatment while still avoiding fines. It can also raise the awareness of end users of their waste generation, thereby encouraging waste prevention, especially of food waste. Home-composters are unregulated however, so while this is economically advantageous, there is concern about the environmental impacts of these facilities if they are not managed properly. For example if they are allowed to turn anaerobic it could result in widespread uncontrolled emissions of methane, and other potentially

hazardous emissions/ nuisance odours. Most studies indicate that home composting does not present a significant risk of methane (Smith and Jasim, 2009) and also it is far less likely that hazardous substances would enter the system as the inputs are managed by the end user. A significant increase in participation rates may also be difficult to achieve as enthusiasts would already have been composting at home and many people who are not already composting may not have a suitable outdoor space or may not feel they have the time to manage a composter. Thus while encouraging this practice is a good start it is only likely to be a small part of the solution.

Centralised composting facilities allow greater control over emissions and reduce potential health risks. However, some composting techniques used on a large scale contain anaerobic zones, where methane production begins very rapidly as some methanogens are tolerant of O_2 (Hobson, 2005). Processes that have more thorough aeration can lead to nitrous oxide formation, a much more potent greenhouse gas than methane. The Defra study (Fisher et al., 2006) considered greenhouse gas emissions from the composting process insignificant, but still found only a very minor improvement over direct landfilling, largely because the process does not produce energy to offset the use of fossil fuels. A move toward renewable and nuclear energy sources in the future may improve the performance of composting compared to energy recovery. There are opportunities to offset the production of fertilisers made synthetically from natural gas or peat which acts as a carbon sink if left undisturbed (Kranert et al., 2008). The nutrient content of composts from household waste is generally too low to substitute these completely, so it is difficult to predict how much benefit this would lead to. The compost produced at a central facility needs to comply with PAS 100 (British Standards Institute, 2005) in order to be used on agricultural land growing food and fodder crops, otherwise it can be used in land remediation products or possibly on industrial crops, however, this is a small market in the UK compared to the land area devoted to food/fodder production and it is likely that some of the low quality composts will end up in landfill. The large number of collection points and the heterogeneous nature of the incoming waste stream will make it difficult to consistently produce a high quality output. Applying compost to land will provide some carbon sequestration and the Defra study attempted to maximise the benefits by taking account of this but it still performed poorly compared to all other waste management methods. In spite of this, it is one of the fastest growing waste management methods in the UK with around 5.1Mt MSW being composted in 2008/09, a

five-fold increase since 1998 (Lets Recycle, 2010b). The reason for its popularity is more likely related to the low capital expenditure, positive public perception, and the fact it is well established, rather than the environmental impacts.

Recovering energy from garden waste through incineration has been found to significantly reduce greenhouse gas emissions compared to landfilling, even with lower efficiency incinerators (Fisher et al., 2006), however, again the electricity fuel mix it offsets has a significant impact on the results. Food waste on the other hand, has a low calorific value and high water content, achieving low energy recovery in incineration.

Anaerobic digestion (AD) is a more effective way of producing energy from food waste but in order to achieve this a high quality feedstock is necessary and is likely to require a segregated food waste collection. Zhang et al. (2010) for example compared AD of mechanically sorted BMW and source-segregated food waste and found that source segregated food waste had a higher energy potential. It should be noted however that the process was less stable with food waste only, due to the production of volatile fatty acids. This meant the mass of waste that could be treated was reduced, compared to mixed waste. A recent WRAP study (Bridgwater and Parfitt, 2008), on separate food waste collection, found a correlation between the success of the scheme and socio-economic demographics. For example areas of high density housing, particularly those with high levels of deprivation had very low participation rates. Lack of participation in a segregated collection may lead to failure to comply with diversion targets and the investment will waste local authority resources. Only one AD plant for segregated food waste has been operating in the UK so far, however, the results have been successful (Chessire, 2007). The government is committed to expanding the use of AD, including for food waste (Defra, 2010a), and it is thus likely to form a significant part of waste management in the future.

Codigestion of food waste with sewage sludge for anaerobic digestion (AD) has been shown to increase the gas production of the sludge, and the use of in sink disposal units, which grind the waste and flush it to sewers has been proposed as a better option for food waste. Various studies (Lundie and Peters, 2005, Evans, 2007) found this disposal route had the lowest environmental impact in terms of GHG emissions. It would also reduce the cost of collection and treatment for this problematic waste stream. In the UK the main problem is that while waste collection and disposal is a local authority responsibility, the water industry

is privately managed and the water companies are concerned about the increased costs they will incur. These issues are discussed in more detail in (Ohandja et al., 2008). Only one local authority appears to have encouraged the use of these so far, however as renewable energy targets come into force the potential financial benefit to water companies may encourage them to accept food waste.

Food waste is also considered a key area for waste prevention. A recent WRAP study (Ventour, 2008) found that 4.6 m tonnes of food waste thrown away from households annually was edible. A campaign to inform the public of the personal financial cost of this has been launched and supermarkets have been targeted to get involved and help bring about a significant reduction of this waste stream.

Residual Waste

Although it has been demonstrated that segregating biodegradable wastes at source generally increases the quality of products and hence environmental benefits, in reality, even with segregated collections available, the biodegradable content of residual waste is still too high to comply with LATS targets if landfilled without treatment. It is the treatment of this residual fraction that is of most interest in this thesis.

The main options for treating the residual fraction are mechanical biological treatment (MBT) or energy recovery through incineration. Although other options have been proposed, such as advanced thermal treatments like gasification and pyrolysis, these have not been taken up by waste management companies in the UK and are still in a demonstration stage, and are unlikely to be commercially viable in time to meet the targets. For example the first gasification demonstration plant, built on the Isle of Wight was closed down in August 2010, due to high emissions of dioxins (Gala, 2010) and the use of district heating from a pyrolysis demonstration plant with planning permission due to be developed in Scarborough was put on hold due to unacceptable risk of investment (Reynolds, 2009).

MBT plants mechanically sort the waste into biodegradable and non-biodegradable components. Most plants attempt to recover metals for recycling using magnets for ferrous and eddy currents for non-ferrous. Others attempt to segregate plastics, glass and even paper and card for recycling as well, although the success of this is questionable, when a source segregated collection is likely to have already captured the high quality recyclables. The

biodegradable fraction is then usually shredded to homogenise the particle size prior to biological treatment, although not always. A summary of possible MBT processes is shown in Figure 2. The remaining fraction is then treated biologically either by composting or anaerobic digestion. Composting is more popular, as it has lower capital expenditure and a proven record of success. AD has only been used successfully in the UK on more homogeneous waste streams, such as sewage sludge and agricultural wastes. It is found to be sensitive to changes in the incoming waste stream (Bajzelj et al., 2010) although when it works it has the advantage of producing methane which can be used for energy generation. Although the heterogeneous and temporally variable composition of MSW is likely to lead to system failures there are MBT companies that claim to be able to practise this effectively.

The compost-like outputs (CLOs) from MBT are a new product in the UK as plants have only been operating for a few years. The sustainability of producing CLOs from a mixed waste stream has been questioned since the implementation of the Landfill Directive (Slater, 2001) due to the likelihood they will end up being landfilled, especially in the early years of treatment, while processes are still becoming established. This is due to a combination of mistrust of the product from both the regulating authorities and potential customers. Only sound scientific evidence will establish whether the outputs are safe to use, and if so effort will have to be put into marketing the product for its reputation to improve. Table 2 shows current MBT plants in the UK. It also includes mechanical heat treatment (MHT) plants, which are similar except the biological step is replaced with an intense heat treatment to produce a refuse derived fuel (RDF) with lower moisture content and higher calorific value. MHT also increases the potential for effective separation of recyclates, as the intense heat will remove labels from plastic and glass bottle and jars, and tin cans, by dissolving the glue. It will also remove most of the food residue on these products (Defra, 2007a).

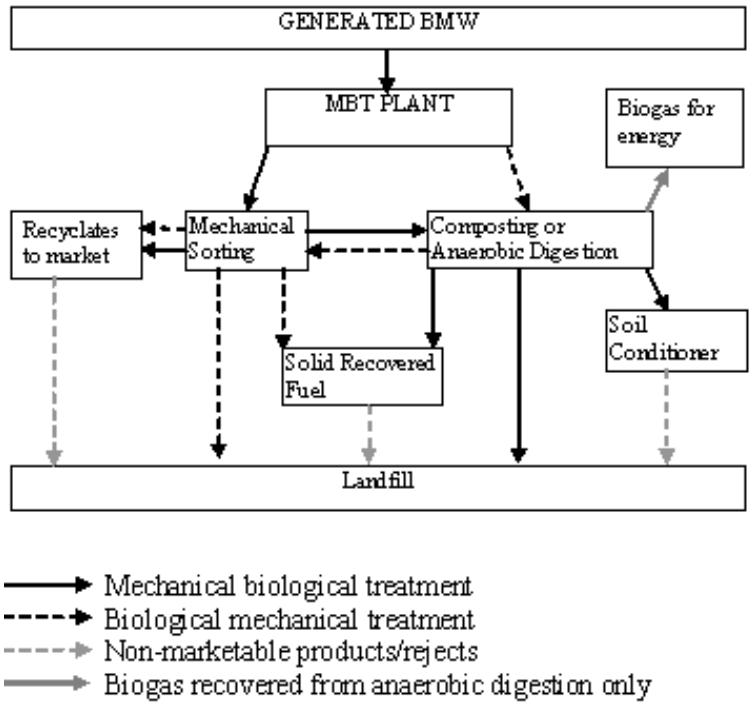


Figure 2: Possible MBT processing options

Table 2: Overview of MBT and MHT sites in the UK (Burgess, 2010)

	MBT	MHT	Total
Operational sites (op)	10	2	12
Sites under construction (c)	2	2	4
Sites with planning permission granted (ppg)	10	3	13
Sites with a planning application submitted (pas)	2	0	2
Sites still in planning (in p)	3	2	5
Rejected sites (pa rejected)	4	1	5
All sites	31	10	41
Total Number of Contractors offering technology	18	5	23
Success Rate	87%	90%	n/a

In Chapter 5 of this thesis the results of analyses of CLO samples from four currently operating MBT plants are presented, alongside a sample of compost from source segregated household kitchen and garden waste and digestate from the anaerobic digestion of source segregated food waste. The final destination of these outputs is somewhat uncertain due to the complex set of legislation that surrounds each option. Broadly, the three main options are landfill, application to land or refuse derived fuel.

Landfill

In chapter 6 the results of the CLO analysis in chapter 5 are used with the GasSim landfill gas simulation model (V1.03) to predict the time taken for gas emissions from landfills accepting significant quantities of CLOs to reach equilibrium i.e. when emissions occur at a rate that allows sufficient natural attenuation in the surrounding environment to prevent environmental harm, so management is no longer required (Hall et al., 2007). A landfill can only really be considered sustainable if it reaches equilibrium within decades, rather than centuries. Management of gas emissions is a requirement of the Landfill Directive Annex 1, paragraph 4 which states:

- appropriate measures must be taken to control the accumulation and migration of LFG;
- LFG shall be collected from all landfills receiving biodegradable waste and the LFG must be treated and used. If the gas collected cannot be used to produce energy, it must be flared;
- the collection, treatment and use of LFG must be undertaken in a way that minimises damage to or deterioration of the environment and risk to human health.

In Germany waste must be reduced in biodegradability to 5mg O_2/g DM based on the Static Respiration Index (SRI) method before it can be landfilled, which is impossible to achieve using current MBT processes. No such limit has yet been established in the UK, and CLOs still count towards LATS. Further there is some disagreement regarding the most reliable and practical method for testing biodegradability, this is discussed in more detail in Chapter 5. The reduced biodegradability and moisture content of MBT treated waste is causing landfill operators and regulators some concern in terms of the effect this will have on the processes controlling gas production, and thus the ability to capture the gas as required by the directive. Knox and Robinson (2007) compared the impacts of landfilling CLOs and incinerator ash. They concluded that incinerator ash was relatively non-degradable and although some unburnt biodegradable material may still be present emission rates would be extremely low and could be dealt with passively. MBT outputs, although reduced in the readily degradable components, degraded slowly over a similar period as untreated waste, leading to gas capture difficulties. Another study (Knox, 2005) suggested that 30-50% of the gas potential of MBT outputs may be released at rates of less than 5m^3/tonne of dry

matter/year. As these rates of gas production decline, the time to reach equilibrium may extend to several decades, and require the use of a support fuel, as the methane content becomes very low, which contradicts sustainability principles. Many models assume combustion of landfill gas cannot be sustained at generation rates of less than $100m^3$/hr. In reality with poor gas collection infrastructure, combustion may actually fail at generation rates of $180m^3$/hr due to low calorific value. Low volume landfill gas flares with re-igniters are available and can deal with gas volumes down to approximately $10m^3$/hr. Landfill sites that experience low level gas generation rates over their entire lifetimes, instead of just at the end, require much greater investment to deal with the gas, without the revenue from electricity generation, making it much less financially attractive for landfill operators. In Chapter 6 these issues are addressed.

Application to land

In Chapter 8 the set up of a second experiment is presented, in which gas emissions at the soil surface of land with CLOs applied were measured using a flux chamber technique. Unfortunately samples were no longer available from the same sources as in the original analysis in Chapter 5, samples that were as similar as possible were obtained. Also there was insufficient time to investigate the longer-term effects of this application. There are two broad categories of application to land: soil conditioner for agricultural land, to improve soil structure and enhance its biological activity, or as a restoration material to reclaimed land, to provide a growing medium for flora. The British Standards Institute has two publically available specifications for application to land in both contexts, PAS 100 for composted materials (British Standards Institute, 2005) and PAS 110 (Waste and Resources Action Programme, 2010) for digestate, however, both of these specify that waste must be source-segregated. Further application to land for growing food or fodder crops is currently only allowed for waste that was segregated at source under Waste Management Licensing (England and Wales) (Amendment and Related Provisions) (No 3) Regulations 2005. However, an exemption can be granted under the European Waste Framework Directive (Parliament & Council of the European Union, 2006b) provided there is sufficient proof that it will cause no harm to human health or the environment. Strictly controlled trials of recycling composted mixed MSW to agricultural land are currently being conducted in

England, aiming to demonstrate no harm will be caused and that there will be a beneficial effect on crop yields (Taylor et al., 2010).

The use of the outputs as a restoration material for reclaimed land has greater scope however, sufficient proof that no environmental harm will be caused is still required together with compliance with Animal By-Products Regulations (ABPR) (Statutory Instrument No. 2347, 2005). The ABPR regulates the collection transportation, storage, handling, processing and disposal of animal by-products not intended for human consumption. There are three classifications of ABP waste. Former food stuffs are listed as category 3, the lowest risk category, meaning it is possible to treat them by composting or anaerobic digestion. To comply with the regulations the waste must be treated at 70°C for at least 1 hour, with a maximum particle size of 12mm in one plane. Any composted waste potentially containing ABP must comply with the regulations unless it is to be used on the site on which it was treated, as long as there is no livestock present.

It is also important to consider that the mechanical stage cannot separate out broken shards of glass, lighter plastics and foils effectively, and these will also be present in the outputs. In particular the presence of broken glass will present a safety risk to people, where this is used on any kind of recreational land.

Solid recovered fuel

The final option of producing a solid recovered fuel (SRF) was also considered. Due to the sensitive nature of this product, companies were not able to provide samples for analysis; therefore this part of the research focussed on marketability, any data were provided by SRF producers. Solid recovered fuel (SRF) is defined as *fuel prepared from non hazardous waste to be utilised for energy recovery in incineration and coincineration plants and meeting the technical specification of the European Committee for standardisation CEN/TS 13359* (Technical Committee CEN/TC 343, 2006). RDF (refuse or residue derived fuel) and ARF (alternative fuels and raw materials) are often referred to interchangeably with SRF, however, these do not necessarily conform to a technical specification and reduce customer confidence in the product. WRATE uses the term RDF, even though some of the processes are known to conform to the specification. Therefore both terms will be used in this thesis, RDF for any processes where the output quality is unknown, SRF for compliant products. In the UK, approximately 450,000 t of SRF is being produced annually. This is mostly used by the

cement kiln industry with 45,000 t being used in gasification plants, 80,000 t in CHP and 18,000 t in pyrolysis. There are a few plants at various stages of planning and construction that could increase annual SRF production by a further 1.5Mt in the near future (Lochab et al., 2010). Encouraging companies to upgrade facilities for SRF use could be achieved through economic incentive schemes, but there are concerns that the CEN/TS limit values are inadequate. These issues will be addressed in Chapter 7.

Energy used in preparing the waste to the technical specification, is often overlooked in impact assessments. An estimate of 30 kWh/t of input material has been suggested (Garg et al., 2007) however, this will inevitably vary between different MBT processing methods and therefore would need to be accounted for on a case by case basis.

SRF is commonly aimed at large industrial plants such as cement kilns, where it can help achieve compliance with a complex set of regulations from both the European Council and regulating authorities in the UK. Compared to the mass burn incineration of raw waste, GHG emissions of SRF used on large industrial sites is often reduced due to improved efficiency, as the heat will be used as well as the electricity, and the onsite use avoids losses associated with transport to the grid; SRF is a better quality product than untreated waste as it has a higher calorific value due to the removal of non-combustible components and some hazardous components are removed improving combustion efficiency and reducing the hazardousness of the air pollution control residues; the controlled particle size of the waste will give better burnout; the recovery of recyclable materials during MBT also reduces GHG emissions; and public perception is more positive due to the high level of materials recovery and reduction of hazardous outputs (Bardos and Chapman, 2008).

Incineration

As mentioned above, incineration is the other option for treating residual waste. In this process the biodegradable content is combusted, leaving two types of ash residues, bottom ash and air pollution control (APC) residues also known as fly ash. The bottom ash is listed as a mirror waste in The List of Wastes (England) regulations (Defra, 2005b), meaning it must be assessed for hazardousness in order to determine what type of landfill it must be disposed to. Landfilling the bottom ash is not likely to generate greenhouse gas as it is a largely non-degradable material (Knox and Robinson, 2007), and further to this will adsorb

CO_2 from the atmosphere, reducing GHG emissions by up to 1%. The adsorption process increases the stability of the material further reducing the environmental impact (Rendek et al., 2006). In some cases it is also possible to recycle the bottom ash into aggregates for use in the construction industry, depending on its hazardous classification. The Waste Incineration Directive (WID) (Parliament & Council of the European Union, 2000b) regulates the emissions control equipment at these facilities and hazardous substances are prevented from being released to atmosphere by air pollution control systems. These leave a hazardous ash residue, which is also classified as a mirror waste. Carbonation of APC residues has also been shown to be an effective carbon sink; for example an investigation by (Baciocchi, 2006) found a storage capacity of approximately 120 g CO_2 per kg APC residue. The recovery of energy from incineration often shows a positive environmental benefit, when it offsets the use of fossil fuels for energy generation. Incinerators are often quoted as having a lifetime of 25 years, in order to prove economically viable. There is a risk that the benefits will become redundant in the future as the mix of fuels for energy generation in the UK appears almost certain to significantly alter to sources with low carbon emissions as the government has made commitments to both increasing renewables and reducing greenhouse emissions (DECC, 2008). This dependence will be assessed in Chapter 4. The benefits are also dependent on the efficiency of the energy generation. Combined heat and power (CHP) has a greater benefit than power generation alone, however, it requires the location of facilities requiring year round high levels of heat, in close vicinity. This will be limited to intense industries unless the plants are built in conjunction with a new housing development. Retrofitting housing for district heating from an incinerator has been shown to be economically unviable (Faria, 2010).

Perhaps the greatest obstacle to the development of incineration in the UK is strong public opposition. Dedicated organisations such the UK Without Incineration Network (UKWIN) have a strong presence in many communities and support from bigger environmental organisations such as Greenpeace, Friends of the Earth and The Green Alliance (Hill et al., 2006). The main arguments they have against incineration are that it will destroy resources that could be recycled into more useful products. Incinerators require long term contracts, on the scale of decades, with a constant annual mass of waste, to be economically feasible, thus there is concern that recycling schemes will be put on hold in order to ensure sufficient feedstock for incinerators. However, reduced input of municipal waste will allow operators of

incinerators to treat commercial sector waste, for which they can charge a higher gate fee. These types of waste are also likely to be more homogeneous allowing the incinerator to run more efficiently, by taking in waste types with higher calorific value, rather than unpredictable MSW residuals. Experience in some other European countries such as Denmark and Germany demonstrates high levels of energy from waste in conjunction with high levels of recycling, therefore there is no evidence for this.

The second main argument is that incineration will lead to significant levels of atmospheric pollutants with adverse impacts on human health. The Health Protection Agency has investigated this possibility and has found that emissions from WID regulated facilities will not lead to significant adverse health impacts (Health Protection Agency, 2009). Similarly, a literature review of epidemiological studies in the vicinity of MSW incinerators found no consistent evidence of adverse health impacts. Although some studies noted higher incidences of certain cancers in the vicinity of an incinerator, there were too many confounding factors to relate the disease incidence to the plant (Porta et al., 2009). Studies are generally conflicting for example, a study by (Cordier et al., 2010) found indication of birth defects in residents in close vicinity to a MSW incinerator in the Alps, while (Federico et al., 2010)b found no link between residents living in the vicinity of an MSW incinerator and illness. It is important to note that these are retrospective epidemiological studies and incorporate periods of time before the WID was implemented, thus are not comparable to the situation in the UK today. Modern plants are monitored constantly by regulating authorities and at the first sign of a breach of air quality limits are shut down and amended before resuming operation.

Landfilling will still provide the ultimate disposal for MSW due to residuals and rejects, but the way landfills impact the environment will change significantly and thus their management must also change in response. Many governments are aiming towards ‘zero waste’ futures and closed loop economies, where landfilling will no longer be practised. The practical implementation of these goals will be considered in the final chapter of this thesis.

2. Aims and Objectives

The overall aim of this thesis is to compare different methods for treating the residual waste stream from households in the UK, with particular emphasis on diverting the biodegradable fraction from landfill. This will be achieved through the following objectives:

Objective 1: Use of the WRATE life cycle assessment (LCA) tool to compare the residual waste stream of twelve waste management systems using the London Borough of Barnet as a case study. The scenarios will include all residuals to landfill, all residuals to incineration and all residuals to MBT. 10 different MBT processes will be assessed with outputs from the biological part of the process varying between landfill, solid recovered fuel, and application to land. The model determines 6 environmental impacts: GHG emissions, abiotic resource depletion, acidification, eutrophication, human toxicity and freshwater ecotoxicity. The comparison will also consider the geographical dependence of the categories whose impacts depend on receptor.

Objective 2: Consideration of the mix of fuels used to produce electricity and use of the WRATE model to determine the environmental benefits of energy from waste. They cannot be altered within an LCA project, and therefore there is a risk that the environmental impacts determined for waste treatment processes that produce energy, will not be valid in the near future. In order to assess the implications of this the WRATE modelling will be repeated with the electricity fuels mix changed from the current UK mix of fossil fuels, to a Norwegian mix, which is high in renewables; French mix which is high in nuclear, with the remainder high in renewables; and the Lithuanian mix, which is mostly nuclear with the remainder fossil fuels.

Objective 3: Analysis of compost-like outputs (CLOs) from operational UK-based MBT plants in order to determine characteristics that will allow modelling of their behaviour in a landfill environment.

Objective 4: Prediction of long term gas emissions from a landfill accepting significant quantities of CLOs, based on the results of the above analysis in conjunction with the GasSim model. This assessment will focus on the GHG emissions impact category, as the UK has

made a regulatory commitment to reducing emission of these gases. The values determined through this modelling will then be compared with the GHG values from the WRATE model.

Objective 5: Assessment of potential markets for CLOs, as solid recovered fuel or soil conditioner for application to land. The WRATE model assumes that all outputs will be used for their intended purpose, however, without a big enough market, unused products are likely to be landfilled, significantly affecting the predicted environmental impacts. The UK solid recovered fuel market will be assessed through a series of interviews with both producers and potential users, as well as a review of the literature. The results of this assessment will be used to predict the quantity of biodegradable household waste that may realistically be diverted from landfill through this use. The application to land market will be assessed through review of the literature.

Objective 6: Investigation of the application to land of CLOs derived from UK-based MBT plants. Samples of CLOs will be applied to land and the gas emissions from the soils will be captured using a flux chamber technique. The gas will then be analysed to determine GHG concentrations for comparison with the values generated by the WRATE model.

Objective 7: Consideration of the possibility of significant changes in waste composition over time, as a result of societal behavioural changes. Two cases will be considered, a residual stream with no food waste, due to the widespread use of in-sink food waste disposal units, and a residual stream with no food or garden waste, due to widespread use of home-composting. Approaches other than LCA to assessing long term waste management will also be considered.

3. Life-cycle assessment comparison of biological waste treatment methods using WRATE

3.1. Introduction

In this Chapter, the first objective is addressed through the results of a LCA to compare 12 different waste management systems. 'Life cycle' is defined in ISO 14044 (British Standards Institute, 2006) as consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. Assessment involves collecting an inventory of the inputs and outputs at each stage of a product's life cycle and comparing the environmental burden based on a defined set of impact categories. As explained in the introduction, LCAs must comprise four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation. The most important part of LCA analysis according to a survey of LCA practitioners is transparency of data. The study should be understandable by an educated non-expert of LCA and reproducible by an LCA expert (Bellekom et al., 2006).

Taking account of the disposal phase of a product's life is important, as shown for example in (Doka and Hischier, 2005) where the incineration of PVC accounted for around 20% of the total environmental impacts. Similar to product LCAs, those for waste management compare options by: identifying and quantifying the environmental emissions and resource use at all stages of the waste management system; taking into consideration the environmental impacts of the different waste management facilities; and quantifying the environmental benefits of materials and energy recovered from waste. The main differences between product and waste LCAs are the definition of the functional unit, which becomes the mass of a unit of waste from a defined geographical area. It could be a mix of many different materials in variable quantities, the only common thread of which is that they are no longer desired for their original purpose (Kirkpatrick, 1996). Each of these materials will impact on the environment in different ways and to a varying extent. The system boundaries are also complicated, as the 'cradle' of the life cycle is when a product is discarded as waste. Extraction processes are only taken into account where recycling or energy recovery are the waste management methods being investigated, so as to account for offsetting benefits these waste management methods may supply. Defining the 'grave' or the point at which waste can be considered to no longer be a risk to the environment is also difficult. In the case of

landfilling this is often defined by a generic time frame of 100 years; however, landfills are estimated to have a pollution potential for longer than this period (Hall et al., 2004). In the case of reprocessing this can also be difficult to define. Taking the example of MBT outputs, where they are to be used as SRF, the final point of the LCA could be the point at which it becomes a marketable product, namely SRF. However, if the product is not sold and used for its intended purpose due to lack of market, it is likely to end up being landfilled. Any impacts associated with storage and landfilling will not be accounted for in the life cycle assessment, even though they will have a significant impact on the environment. Therefore the 'grave' must be the point at which SRF is used. Thus in order for potential impacts to be realistically accounted for, the definition of the 'grave' point in waste management LCA must be determined on a case by case basis.

Since the development of LCA for waste management, many software tools have sprung up for this type of analysis. In 1998 the International Expert Group on Life Cycle Assessment for Integrated Waste Management was established, and they published a report comparing six LCA tools developed for waste management (Winkler and Bilitewski, 2007) in an attempt to show that variations in the results of the different tools are within acceptable limits. The study found that the models failed to allow for realistic representation of waste management processes, due to the large numbers of assumptions, especially those relating to linearity, i.e. changes over time. Therefore even though LCAs are conducted according to the international standard methodology (ISO 14044) it does appear that there could be some further harmonisation of approach, to provide more confidence in the comparison of results of such studies. The limitations will be investigated in more detail in Chapter 9.

The comparison presented here focuses on treatment options for the residual fraction of municipal solid waste, after a kerbside source-segregated collection. The reason for this is that source-segregated kerbside collections are already well established in the UK, however, the residual fraction is still too high in biodegradable content to landfill without treatment. Options for treating the mixed residual waste fraction are limited by the nature of the waste. Only two technologies are available that have a proven track record from other EU member states, energy recovery through incineration or mechanical biological treatment (MBT) with outputs either landfilled, SRF or applied to land. The UK Government's sustainability

principles (Defra, 2008b) will also be taken into account, which require an environmentally beneficial option that does not cause unnecessary economic or social burden.

3.2. Description of WRATE

Goal and scoping and functional unit

The functional unit is mass of annual waste generation, the waste composition being defined by the user. The breakdown of waste categories is shown in Table 3. A default waste stream is available in the model; however, it is still necessary for the user to define the mass of total waste arisings. The population of the region being studied and average persons per household must also be provided. One of the key issues in waste management is the advantage of energy recovery over other waste processes due to its ability to offset other power generation technologies. Electricity mixes are contained within the model for most countries in Europe, including a breakdown of the four countries of the UK and the UK average.

The system starts at the kerbside, with waste being allocated by the user to desired bin types. Transport options are available for the next stage, to collect and transport the waste to the various treatment facilities. Data on road, ship and train are available; the user is only required to define the distances, as an average per trip, or cumulative annual distance and the road type as urban, rural or motorway for road vehicles. Intermediate facilities such as materials recovery facilities, waste transfer stations and civic amenity sites are available. Treatment facilities cover incineration, composting, MBT, anaerobic digestion and advanced thermal treatments. All of these have internal reject rates that are sent to landfill by road with an average distance of 50km, which are predefined by the Environment Agency. There are restrictions on the incoming waste to each process, to make sure only appropriate wastes are sent to each technology and outputs which must be sent on to further processes. The final destination processes are the recycling plants, landfill, or land application. All waste types must be carried through the flow of processes until they are recycled, landfilled or applied to land. In the case of incineration there are ashes to be disposed of and the potential for further recovery of metals or recycling of bottom ash into aggregate. As with the treatment facilities, each recycling option has an assumed reject amount sent to landfill by the model. The user has the option of altering these if desired.. The model will also determine any benefit of recycling over extracting raw materials. As far as possible, data in the model was gathered by

ERM (Environmental Resources Management) on behalf of the Environment Agency, with all other data taken from Ecoinvent version 1.2 (Environment Agency, 2007). The calculation of benefits of energy recovered from waste is based on the chosen marginal electricity mix, as opposed to the baseline electricity mix. The baseline provides a constant level of power, while the marginal provides power when demand exceeds the baseline.

Inventory analysis

WRATE differs from other LCA tools in that all the inventory data for each process is already programmed into the model. Data is included for all stages of waste management including waste receptacle; transport including road vehicles, shipping, trains; intermediate facilities such as transfer stations and materials recovery facilities; treatment facilities such as recycling plants, incinerators, mechanical biological treatment plants; recycling plants; and landfill. The user is only required to input information relating to the composition of the waste stream, and tell the model where to send the outputs from each processing stage. A typical example is illustrated in Figure 3. This simplifies the LCA process as only the goal and scoping stage, impact, and interpretation are required to be performed by the user.

Impact analysis

WRATE includes 6 different impact categories as described below. The results can be represented by characterisation factors or the normalisation factor 'euro person equivalent' which relates each impact to the annual emissions of an average European person.

Greenhouse gas emissions

Greenhouse gas (GHG) emissions are measured as $kgCO_2$ equivalents. The main contributing pollutants are CO_2, methane CH_4 and nitrous oxide N_2O. It was the first impact category to achieve consensus among the scientific community (Bare, 2010). The method for quantifying these impacts was developed by the International Panel on Climate Change (Bogner, 2008). It is a relatively straightforward calculation, determined as total emissions predicted per year. For landfills, predicted emissions are generally based on decomposition factors, as in the GasSim model (V1.03). IPCC defines it as 'rate of energy change per unit area of the globe as measured at the top of the atmosphere'.

In WRATE a lifetime of 100 years is used to define the extent of increased radiative forcing by 32 greenhouse gases. Emissions are divided into biogenic or fossil where appropriate. Biogenic emissions do not contribute to the total GWP100 score, as they are considered part of the natural carbon cycle.

Abiotic resource depletion

Abiotic resource depletion is measured in kg Antimony equivalents. It broadly entails energy, metallic minerals and the ability to extract those minerals, which have only functional value to humans, i.e. they are valuable because they enable us to achieve other goals that have intrinsic value, such as human welfare, human health or existence values of the natural environment (Yellishetty et al., 2009). Conceptually it is the most difficult of the impact categories to define as the value placed on a certain material will differ both temporally (things essential to our life style may be redundant for future generations when products are made with different materials or new products emerge to replace them) and spatially (things valued in developed countries may differ dramatically from less developed countries (Stewart and Weidema, 2005, Steen, 2006)). Deciding on what resources are valuable and need to be preserved depends on what we value now and what we believe will be valuable in the future. This applies to both the economic value and the environmental cost of not having these substances available for future generations. It depends on the presence of a user, the needs and skill of the user, expectations about the future and perceptions about what constitutes the depletion problem.

Resource depletion has been included in LCA analysis since the early 1990s and it is widely agreed among LCA practitioners that inclusion of this impact category is important (Udo de Haes, 2006, Yellishetty et al., 2009). However a consistent methodology is yet to be developed for quantifying the effects (Yellishetty et al., 2009). Various approaches used to quantify the category, which consider a combination of current consumption and predicted future requirements, have been reviewed by The Society of Environmental Toxicology and Chemistry (SETAC) group in the IA-2 report (Lindeijer et al., 2002 via Stewart and Weidema, 2005). Some approaches include: limits of mining cost; collecting metals or other substances from low-grade sources as resources become depleted, especially the energy requirements of this; scarcity; and environmental impacts from mining and processing of mineral resources. The representation of the impacts has also been investigated as energy or

mass, relation of use to deposits, future consequences of resource extractions, exergy consumption or entropy production (Guinée and Heijungs, 1995, Strauss et al., 2006). Stewart and Weidema (2005) proposed the elements required for determining impact are a functionality indicator, an ultimate quality limit and backup technologies.

The one commodity that is unarguably essential for all is energy, as this is required in order to extract all other substances from the earth's crust. It is an interesting example of resource depletion. Energy is obviously extremely valuable for sustaining our quality of life and currently is largely supplied by carbon-based fossil fuels, which have only a single use value, i.e. once they have provided energy they are converted to a form that is no longer useful. However, energy will always be available on earth as long as the sun is shining; it is just a matter of developing the ability to harness that energy into a functional form.

In WRATE the inventory of impacts for resource depletion consists of 64 abiotic substances covering metals, gem stones, and energy sources including coal, oil, gas, and uranium.

Human toxicity

The characterisation factor for human toxicity is based on an environmental fate-exposure-effects model. The exposure routes incorporated are inhalation through air, in both urban and rural settings; ingestion of drinking water and untreated fresh surface water; leaf crops (exposed produce); root crops (unexposed produce); ingestion through meat, milk and fish (both freshwater and ocean)(Rosenbaum et al., 2008). The calculation is the increase in the amount of a compound transferred into the human population based on the concentration increase in these different media.

A linear dose-response relationship is assumed for each disease endpoint and intake route. The quantity taken in through inhalation or ingestion is related to the probability of adverse affects. The probability is determined through toxicological studies on animals, with the results being scaled up on a per kilogram basis. Differences in metabolic processes are not considered. The factor is determined as the quantity at which effects are seen in 50% of the population known as EC_{50} with units of number of cases per kilogram of intake. Effects are categorised as cancer or non-cancer for both exposure routes.

The USEtox database has characterisation factors for 991 organic substances (with 260 interim factors.) The interim factors are those which are not subject to the same level of research but are provided as a rough estimate (Rosenbaum et al., 2008).

In WRATE 142 substances are included in the impacts output, to air, water and soil. They are measured as kg 1,4 Dichlorobenzene (DCB) equivalents.

Freshwater ecotoxicity

The exposure routes considered in the case of freshwater toxicity are direct emissions to the water environment, deposition from the atmosphere and leaching from soils. The freshwater ecotoxicity characterisation factor is determined in a similar way to the human toxicity factor. Similar to humans, receptors in the environment each have an EC_{50}, (dose at which effects are seen in 50% of the population). For the LCA impact category a HC_{50}, the dose for which 50% of species' EC_{50} is exceeded, is used. The units in this case are usually m^3/kg.

The USEtox database has characterisation factors for 1299 substances, and 1247 interim factors. Factors have only been calculated for freshwater as the oceans are considered a sink for pollutants, in the LCA framework defined.

In WRATE 134 substances are included in the output table, measured as kg 1,4-DCB equivalents. There is some overlap in substances with human toxicity, but the level of impact differs, due to different sensitivity of receptors.

Acidification

In contrast to GHG emissions, the significance of acidification impacts is very dependent on geographical location. The impacts due to acidifying pollutants are long range, meaning they will occur far away from where emissions are released. The significance of the impacts will depend on the sensitivity of the area where it finally settles, and any natural buffers that exist in that region. For example in the southern part of the UK, the ground is very calcareous and will naturally buffer acidity, meaning little impact will occur to plants, while in places like Sweden the impacts on vegetation are highly significant (Bellekom et al., 2006). Therefore it is important to consider that the significance of impacts will depend heavily on the location where the emissions are released; high level emissions in some place may not

cause significant damage, while in other areas, low level emissions will. A study that looked at improving the reliability of the impact category by including more location specific data (Bellekom et al., 2006) found that the overall significance of the impact category was unaffected, however, the relative contribution of basic processes changed. The most difficult part of the work was disaggregating the basic processes making up the database the information was taken from. However, in general only one or two processes contributed to the majority of emissions, and also the disaggregation only needs to be performed once, the data can then be used in subsequent projects.

Hettelingh et al. (2005) derived characterisation factors for acidification for 26 European regions, the EU nations, except Malta and Cyprus, plus Switzerland and Norway. All other European countries were evaluated as a single region. These characterisation factors were dependent on year of emissions release, atmospheric transport model, area and vulnerability of receptors or ecosystems. Source-receptor matrices related national emissions (sources) to 150 by 150 km^2 grid cells covering Europe (receptors) in which there are around 1.5 million ecosystem sites identified by their critical loads. Both acidification and eutrophication impacts are dependent on sensitivity of receptors. A study by Posch et al. (2008) considered 3 approaches to calculating the results of these two impact categories. The first approach was to determine total emissions of relevant pollutants which provided a good first approximation to the impact category but can overestimate the significance if the pollutants are deposited in an urban environment for instance. Secondly they extended the approach to incorporate a spatial component, by applying atmospheric dispersion modelling. This provided a first step to improving the results, however still failed to take account of receptor sensitivity. Further to this, they did not account for depositions into the ocean (a sink) or areas outside of the investigated zone. The final approach incorporated critical loads data of the different receiving ecosystems and provided the most reliable results for impact significance.

The main limitations to this approach are that data on receptor sensitivity are not available for many places outside Europe, limiting studies to this area. The long range nature of these pollutants makes the reliability of the results problematic.

In WRATE acidification impacts are emitted to air only. The inventory includes ammonia, NO_X, SO_2 and SO_X and is measured as kg SO_2 equivalents.

Eutrophication

Eutrophication is excessive growth of surface species in waterways, which decreases biodiversity, reduces aesthetics and drinking water use. It occurs when large amounts of nutrients, especially nitrogen and phosphorus, enter the waterway causing algal species to multiply rapidly. This is a nuisance in itself and also algae absorbs oxygen from the water and blocks sunlight causing plants species that live below the surface to die. Eutrophication impacts are very complicated to calculate as, similar to acidification, the impacts are dependent on the sensitivity of the area where they end up and, like the toxicity categories, there are multiple pathways for the pollutants to reach receptors. Further to this, biological availability of the nutrients that cause eutrophication will be dependent on their chemical composition on release, and the time of year when they reach a receptor must be taken into account as the growth of algal blooms often requires sunlight (Seppala et al., 2004).

The pathways include direct release into waterways, deposition from the atmosphere or leaching from soils. Pollutants can reach soils either through deliberate application to enhance crop growth, or atmospheric deposition. The fate processes depend on different characteristics of the emitting source, environmental media, and receiving environments. The impacts depend on background loads and different sensitivities of individual ecosystems. Separate nutrients may limit growth in different ecosystems.

In WRATE the impact outputs include 16 chemicals containing either nitrogen or phosphorous, as kg PO_4 equivalents, emitted to air, water and soil.

3.3. Method

As mentioned in the introduction, the functional unit in WRATE is defined as a mass of mixed waste. The composition of the waste stream used here, is based on the percentages published by Defra (Resource Futures, 2009), detailed in Table 3. The categories are in bold and the subcategories in normal font. Please note there are other categories in the model but only relevant ones have been included here. The categories published in the report did not exactly match those in the WRATE model, so where the exact category was not present, the mass was allocated to the closest 'unspecified' categories. Mattresses were included with 'furniture'. Metals were not categorised in the report, therefore 50% was allocated to ferrous and 50% to non-ferrous. Similarly textiles were not broken down any further so 50% was

allocated to natural and 50% to synthetic. This agrees with the assumption in the report that the biodegradability of the textiles category is 50%. The category ‘sanitary’ in the report was assumed to be the same as ‘absorbent hygiene products’. Finally the ‘other waste’ category in the report was split 50:50 between ‘other combustible’ and ‘other non-combustible’ in the WRATE input table.

The London Borough of Barnet was used as an example region for the assessment. Its population is 331,552, and the number of households is 126,944, 61% terraced, detached or semidetached and 39% flats in a converted building, purpose built block or other (Capital Waste Facts, 2010). Waste generated in Barnet is 443 kg per person, slightly below the national average of 495 kg per person (1072kg per household) (Resource Futures, 2009) and the residuals fraction 295 kg per person (669 kg per household). The total waste generation for this project was thus determined as (0.443 x 331,552) = 146,878 t.

Twelve scenarios were modelled. The first scenario ‘all residuals to landfill’ is shown in Figure 3. As can be seen four different collections were taken from the kerbside, as carried out in the London Borough of Barnet: A recycling box with lid for glass, paper and textiles (other hazardous wastes allowed for in this collection were not included and were sent to the residual stream); a recycling box without lid for hard plastics, plastic bags, card, tins and aluminium; a green waste bin for garden and kitchen waste and finally a residuals bin. For each waste type sent to each process it was assumed a certain amount of each waste type would be included with the residuals shown in Table 4, as happens in reality. These values are taken from two Open University studies (Jones et al., 2008a, Jones et al., 2008b) except for textiles for which no data was available. Capture rates in the recycling stream for textiles was assumed to be relatively low due to the prominence of reuse opportunities and lack of public knowledge about the availability of this service, which was assumed to be similar to that of food waste. Therefore 20% was assumed. Green waste bins are only provided to 91,246 households, and of these only 55,954 participate. Thus this value was used in the model as the number of greenwaste bins collected weekly. The two recycling boxes and residual bin are provided to all households, thus these were the same in all scenarios.

Table 3: Waste composition for London Borough of Barnet case study (Resource Futures, 2009)

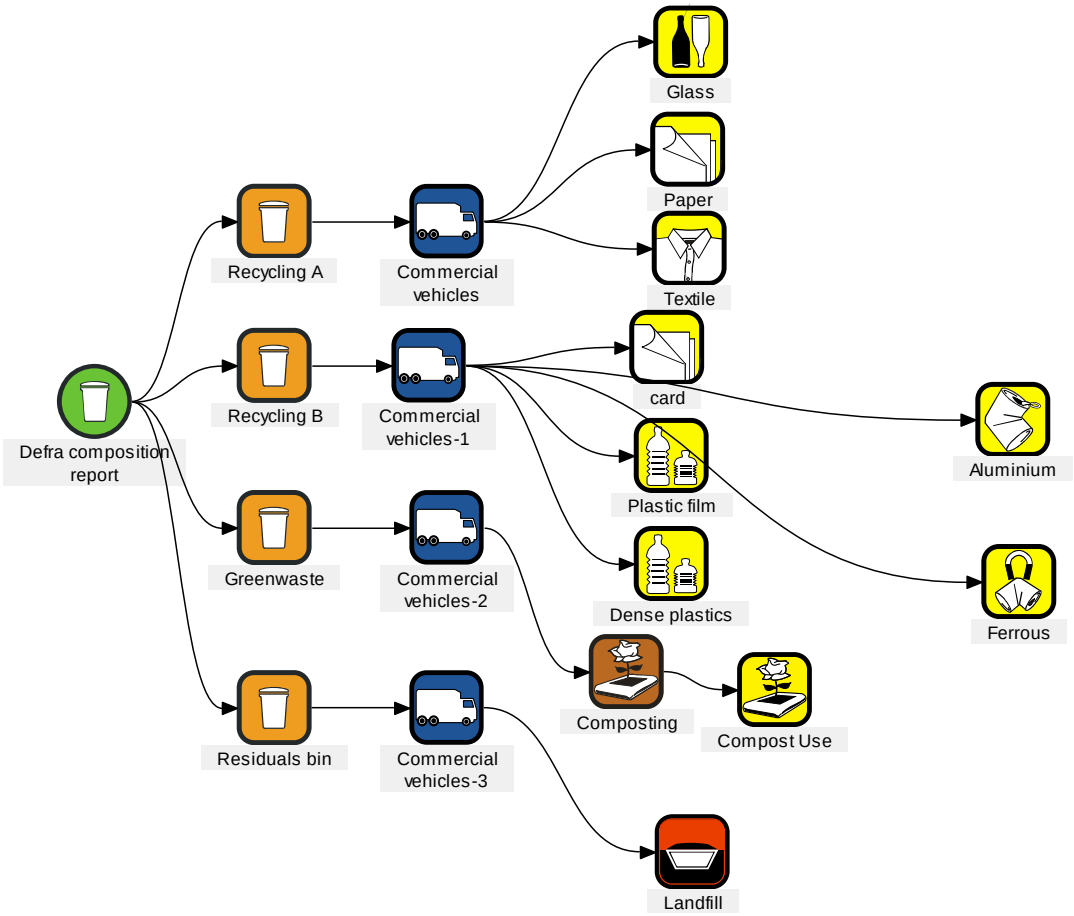
Waste Fraction	%	Quantity [tonnes]
Paper and card		
Unspecified paper	16.7	24452
Other card	6.0	8870
Plastic film		
Unspecified plastic film	4.3	6321
Dense plastic		
Drinks bottles	1.7	2499
Other packaging	2.4	3528
Other dense plastic	1.6	2352
Textiles		
Synthetic textiles	1.4	2080
Natural textiles	1.4	2080
Absorbent hygiene products		
Unspecified absorbent hygiene products	2.5	3690
Wood		
Unspecified wood	3.7	5477
Combustibles		
Unspecified combustibles	2.4	3481
Furniture	1.6	2342
Other combustibles	1.2	1705
Non-combustibles		
Unspecified non-combustibles	2.8	4140
Soil	0.2	270
Other non-combustibles	1.2	1705
Glass		
Unspecified glass	6.6	9753
Organic		
Garden waste	14.1	20678
Food waste	17.8	26205
Other organics	1.7	2541
Ferrous metal		
Unspecified ferrous metal	2.2	3155
Non-ferrous metal		
Unspecified non-ferrous metal	2.2	3155
Fine material <10mm		
Unspecified fine material	1.7	2431
Waste electrical and electronic equipment		
Unspecified WEEE	2.2	3216
Specific hazardous household		
Unspecified hazardous household waste items	0.5	774

Table 4: Assumed percentage of recyclables in residual waste stream

Waste type	Paper	Card	Plastic	Glass	Metals	Textiles	Garden	Food
% to residuals	14	31.7	63.0	37.3	34.8	80	49.4	77.8

Figure 4 shows the process flow map for the second scenario 'all residuals to incineration'. Transportation type and distances are constant in all scenarios. Although there is some argument that landfills will typically be located further from waste sources than treatment facilities, assessment of this was beyond the scope of this LCA. The incinerator contains data from Sheffield district heat and power. The choice of incinerator was based on relevant size for the amount of waste being collected in this example region, and also having CHP, rather than just power generation, as this is encouraged by the Waste Strategy for England (Defra, 2007b) which states "Any given technology is (where applicable) more beneficial if both heat and electricity can be recovered. Particular attention should therefore be given to the siting of plant to maximise opportunities for Combined Heat and Power."

For the remaining 10 scenarios the residuals bin was sent to ten different MBT processes contained within the model. The external management tab was used to decide the final destination of each waste type. A brief description of the MBT processes can be found in Table 5, and Table 6 shows the biological stage and main outputs. More complete information about the processes can be found in Appendix A. Anything not included in the product column of the output table was sent to landfill without any further treatment. Anything under the product column was sent to the most beneficial process, for example paper sent to paper recycling, CLOs to compost, RDF to a cement kiln. As explained in the introduction the model has built in reject rates for each type of recyclable or recovered waste, based on data gathered from the facility being modelled. Although it is possible to alter these values in the model, investigation of varying the reject rate was beyond the scope of this study. Any wastes in the product column that had no other option for reprocessing in the model were sent to landfill, especially 'stabilite', which appears under both the product and reject column in different scenarios. However, currently this has no other use and can only be landfilled.



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Database Version 2.0.1.4

Figure 3: Waste management process diagram for residuals to landfill scenario

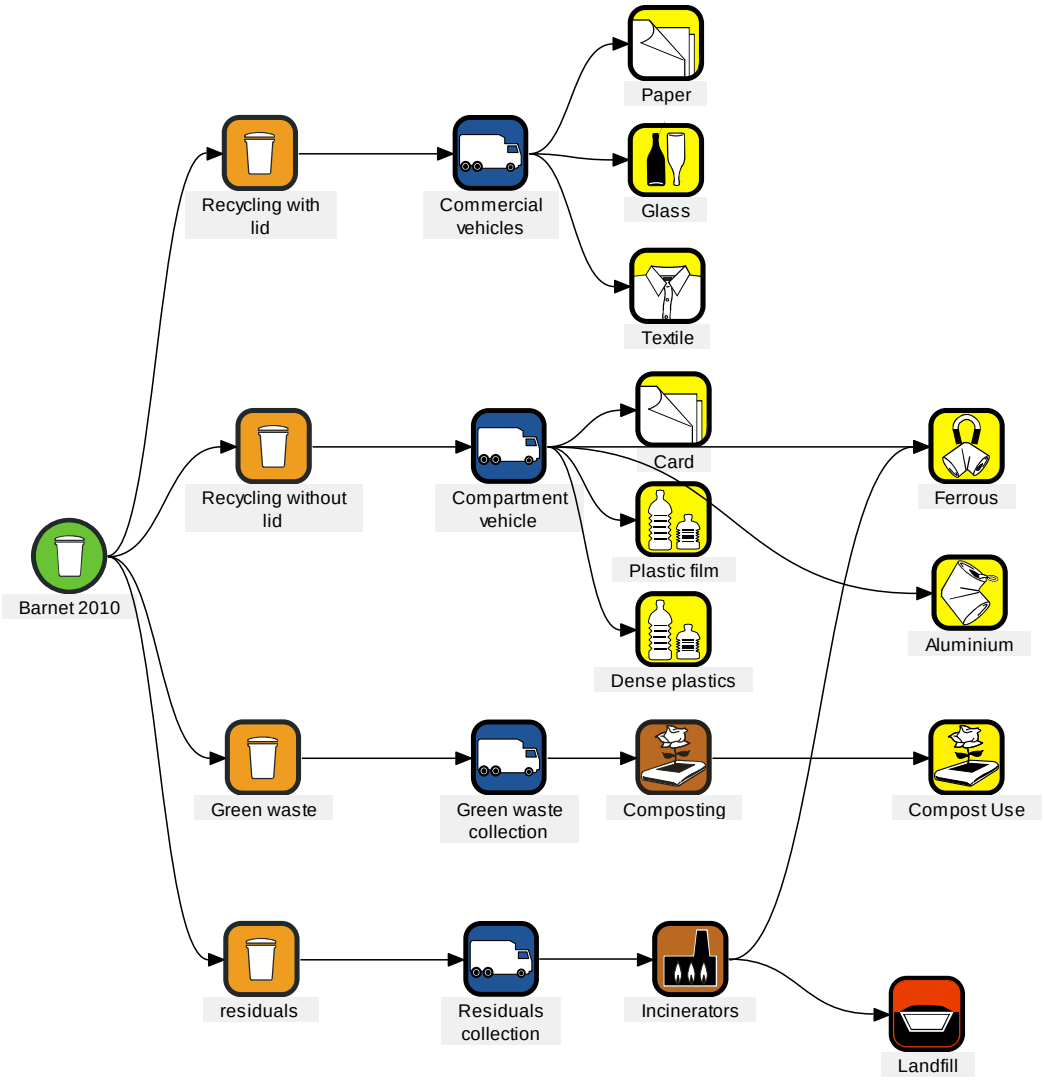

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Figure 4: Waste management process diagram of residuals to incineration

The results were generated in terms of characterisation for each of the 6 impact categories and copied into an excel spreadsheet. Graphs showing the percentage change between each MBT type and landfilling and incineration were then produced and are discussed for each impact category below. Graphs showing the relative contribution of each process of the waste management system are also shown to indicate what part of each process contributed to the overall impacts.

Table 5: Description of MBT processes (Environment Agency, 2007)

Process	Description
Haase	The waste is screened and separated into different substances. The biodegradable fraction is then suspended in liquid to achieve 10-15% dry matter. Light density material and medium solids are then separated to produce a substance suitable for AD. After AD and oxidation the liquid is separated and returned to the liquid suspension stage, and the solids are dried and either processed to produce RDF or landfilled.
Arrowbio	Organic and inorganic material is separated using a liquid-based technology, involving gravitational settling, screening and hydro-mechanical shredding of organic solids. During this process glass, metals and large plastics are separated for recycling; hazardous materials are removed gently to avoid breakages; and the organic fraction is prepared for AD. The organic fraction is then put through a two-stage AD process. The liquid is recirculated through the system to maintain the solids content, with any excess released to sewers. The biogas is fed back into the system to stir the AD, and excess gas is used to produce electricity. The solids are dewatered and used as a soil improver or landfilled.
Global Renewables	Hazardous and other incompatible waste is removed by hand, before passing it through a bag opener and trommel screen to separate it into two size streams. The smaller fraction is passed through a 2nd trommel and an air stream to remove light paper and plastics from organic wastes. The oversize materials are passed through various mechanical separation stages to separate as much recyclable material as possible. The remainder is shredded and passed through trommel to separate into two sizes with the oversize sent to landfill the smaller fraction goes into a ISKA Percolator process for two days, to prepare for AD. The material is then digested using a continuously stirred system. The remaining material is either treated for application to land or landfilled.
Ecodeco	Upon receipt the waste is inspected and any undesirable items removed, using an automated crane. It is then fed into a shredder to produce a homogenous material suitable for biological treatment. The material is placed into heaps and biodryed for 24 hours, before a mechanical separation stage, which removes metals, and other non-combustible material. The remaining fraction is shredded and either refined to produce RDF or landfilled.
Entsorga	The waste is passed through a rotary drum, which opens plastic bags, and removes oversize material, especially plastics and card, which can be recycled. The remainder is placed in windrows and aerated for 10-14 days. Following this, metals are removed and the material is either processed to produce SRF using shredders, screens and air classifiers, or landfilled.
Herhof	Waste is shredded to particle size of < 150mm, ferrous metals are removed, and the rest is transferred to composting boxes. The six day composting process focuses on heating the material to remove as much moisture as possible. The material is then passed onto densimetric tables and different materials are separated by weight. Heavy materials such as metals, glass and ceramics are removed for recycling, while the lighter material is processed to produce an RDF.
Bedminster	Unsuitable items are removed from the waste stream by visual inspection before placing the material in a rotary drum digester, where biostabilisation of the organic fraction occurs. The material is then passed through a trommel screen to produce two size streams. The smaller stream is processed to produce RDF. The larger stream is passed through mechanical processes where metals and glass are separated for recycling, any combustible materials are shredded and added to the fuel, and inert materials are landfilled.
Linde	Oversize material is removed from the waste stream and landfilled. The waste is then passed through a shredder, metals are separated for recycling and the remainder is trommel screened to produce two size fractions. The undersize fraction is composted for four weeks in tunnels, and screened to produce RDF. The reject fraction is landfilled.
SRS	The waste is passed through a bag opener and then trommel screened into two size streams. The oversize is passed through further mechanical separators, including magnets, density separators and conveyors producing bottles, cans, plastic, cardboard etc for recycling. The undersize fraction is also passed through magnets to remove as much metal as possible, before being moved to a fully enclosed flow through tunnel composting system.
VKW	Unsuitable material is removed using a gripping excavator, before shredding. The shredded material is sieved into three size fractions. The largest fraction is passed back through the shredder. The fine fraction is passed through magnets to remove metals, and then composted on a moving table windrow system, for six weeks, including a maturation phase. The intermediate

fraction is passed through a ballistic separator producing three weight and size fractions. The light-flat fraction is used for RDF, the intermediate is manually sorted with suitable parts separated for recycling, and the fine fraction is sent to the composting process.

Table 6: Outputs from MBT processes

MBT process	Biological treatment	Total output (t)	% product	% RDF	% stabilite	% recycled
Haase	AD	9.5E+06	21.3	15.5	78.7	1.4
Arrowbio	AD	1.3E+07	50.8	0.0	35.2	15.6
Global Renewables	AD + compost	1.2E+07	52.3	0.0	32.7	19.7
Ecodeco	Biodrying	1.1E+07	63.8	50.9	0.0	4.1
Entsorga	Compost (biodrying)	1.1E+07	76.0	66.7	0.0	0.8
Herhof	Compost (biodrying)	1.0E+07	94.1	73.7	0.0	13.4
Bedminster	AD + compost	9.8E+06	79.6	25.3	0.0	1.0
Linde	Compost	1.3E+07	60.9	45.0	30.9	0.1
SRS	Compost	1.1E+07	100.0	33.7	0.0	30.4
VKW	compost	1.1E+07	97.5	6.6	86.0	1.9

3.4. Impact assessment and interpretation

The results from the 6 impact categories are shown and discussed below. The discussion for each is split into 3 sections: i) recycling, shown in yellow, ii) treatment and recovery, shown in blue, and iii) landfill shown in pink. In the figures a negative value indicates a net environmental benefit, while a positive value indicates and net environmental burden. As mentioned previously, recycling impacts are determined by comparing the environmental impacts of reprocessing the waste type, with its raw production. Thermal treatment impacts are calculated by comparing the burdens of the thermal treatment process with the marginal electricity mix defined by the user. Landfill burdens are more complex as they vary by waste type. The model divides waste into 4 categories: 1. MSW, 2. Wastes that mimic MSW, especially ‘stabilite’, 3. ‘special’ wastes which are non-degradable and are not likely to contribute to gas generation, but have some properties that could dissociate into leachate posing a risk to waterways, e.g. incinerator bottom ash, 4. Waste which cannot be landfilled; the model does not allow for this route.

The gas generation for category 1 and 2 waste is determined by a linear regression model, based on the Environment Agency models GasSim and LandSim. As different types of waste will make a different contribution, the model contains a set of loading factors, values between 0 and 1, which reduce the mass of the waste fraction, according to its likely contribution to environmental burdens. For example glass has a loading factor of 0 as it is inert and will not contribute to either leachate or gas generation.

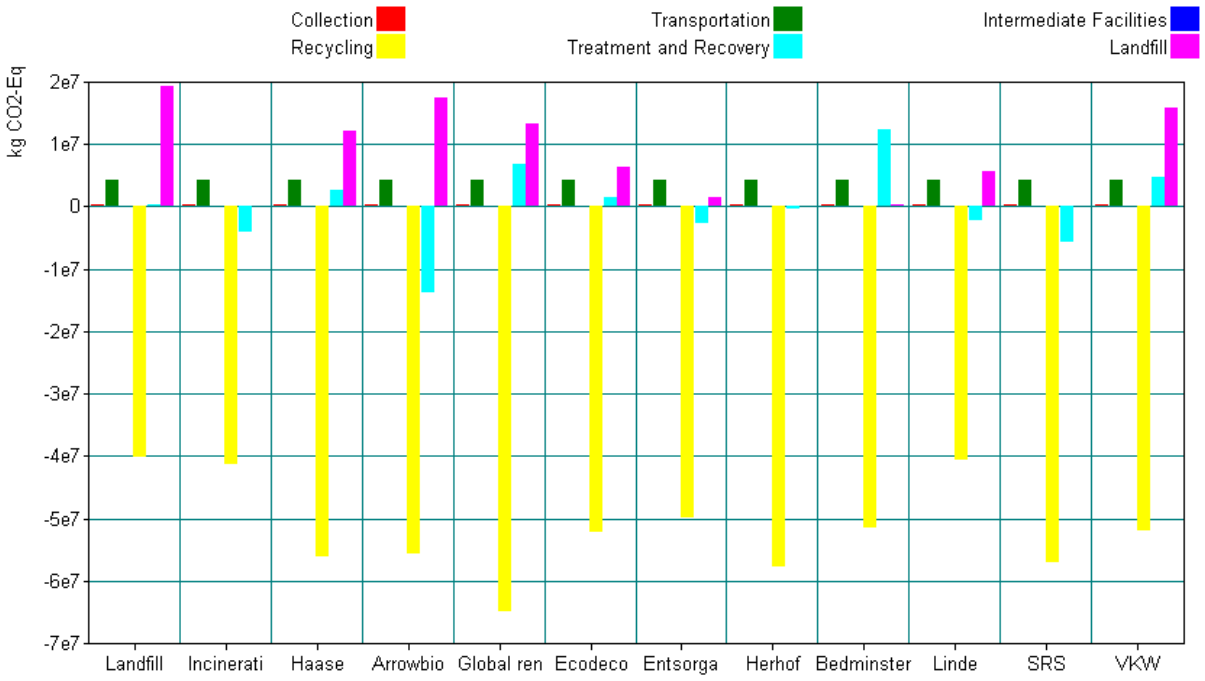


Figure 5: Greenhouse gas emission impacts by process

Greenhouse Gas Emissions

Figure 5 shows the breakdown of GHG emissions impacts by process. Tables of emissions by pollutant are available in Appendix B. As explained in the method, 'collection' and 'transportation' are the same for all scenarios and this can be seen here as the impacts are identical. No 'intermediate facilities' were considered, and therefore no impacts are seen. Intermediate processes will therefore not be considered in the rest of the discussion.

The recycling impacts are almost identical for landfill, incineration and the Linde process. The landfill scenario offers no recycling from the residual waste stream, thus its impact indicates the baseline benefit from the source-segregated kerbside collections. Incineration and Linde MBT offer only a small amount of ferrous metal recycling, thus, this route

demonstrates no significant improvement. All other processes have more significant recycling capacity and therefore reduced GHG emissions. Figure 5 indicates that the greatest recycling benefits result from Global Renewables and the SRS process. This is interesting as Table 6 indicates SRS recycles around 10% more than Global Renewables. However, looking at the breakdown of recyclables (See appendix A), Global Renewables recycles nearly twice as much metal as the other processes. Metals extraction has a very high GHG emission potential, compared to reprocessing, thus recycling of this component is likely to have a greater benefit than more recycling of other components (Fisher, 2006). SRS focuses more on plastics and paper which have relatively energy intensive reprocessing and therefore they would be expected to have smaller benefit over raw production.

In the treatment and recovery process, Global Renewables has a much worse performance than most other processes, as the high level of separation required to obtain such high levels of recyclates is energy intense. The offset between the recycling benefit and such an energy intensive treatment process therefore determines the net impact. Bedminster has the highest GHG emissions during treatment and recovery, again indicating an energy intensive treatment process. N_2O can be emitted during composting through nitrification and denitrification processes. Its potential impact on global warming, according to IPCC guidelines, is 296 times that of CO_2.

In terms of landfilling, as expected, all waste to landfill has the worst performance, followed closely by the Arrowbio process. Although this MBT process had around 50% 'product' according to the model, most of this was stabilite, which can currently only be landfilled. As explained the burdens of landfilling this waste type are considered equivalent to MSW. Similarly, all the other significant GHG emissions from landfill are from those facilities that produced stabilite. Processes with the lowest emissions from landfill are SRS, which sent no waste to landfill, Herhof, which produced mainly RDF and Bedminster which also sent very little waste to landfill. The impacts from incineration, and thus RDF are very low as only non-biodegradable ashes would be landfilled in this case. As described in the introduction, studies have shown that incinerator ash can actually absorb some CO_2 from the atmosphere (Rendek et al., 2006, Baciocchi, 2006) to give a net negative impact but the model does not take this into account.

The GHG emission potential from landfill, as calculated by the model fails to account for a few factors that could affect the results. This includes the fact that landfill offers some opportunity to sequester carbon, especially in terms of non-biodegradable plastics which will be buried in the ground and preventing the release of CO_2 to the atmosphere. The extent to which the model takes this into consideration is unclear.

Landfill gas also provides a renewable energy opportunity and at the time of writing provides approximately one third of the UK's renewable energy. The extent to which the model takes account of this is described in Hall et al. (2005). In general the gas generation is based on mass of effective incoming biodegradable waste, using loading factors, similar to those used to calculate the burdens. Wastes that fall under category 3 in WRATE, including incinerator bottom ash and air pollution control residues, are assumed to have 0 gas generation potential and therefore do not contribute to energy production. The size of the landfill is also taken into account, as smaller landfills will not produce enough gas to run a turbine engine.

Slowly degrading components, especially 'stabilite', have been shown to generate gas slowly over a long period of time. Such low level generation rates are difficult to capture, and increase the risk of release to atmosphere. Emissions due to the biodegradable waste fraction from MBT in landfill will be investigated in Chapter 6.

Abiotic Resource Depletion

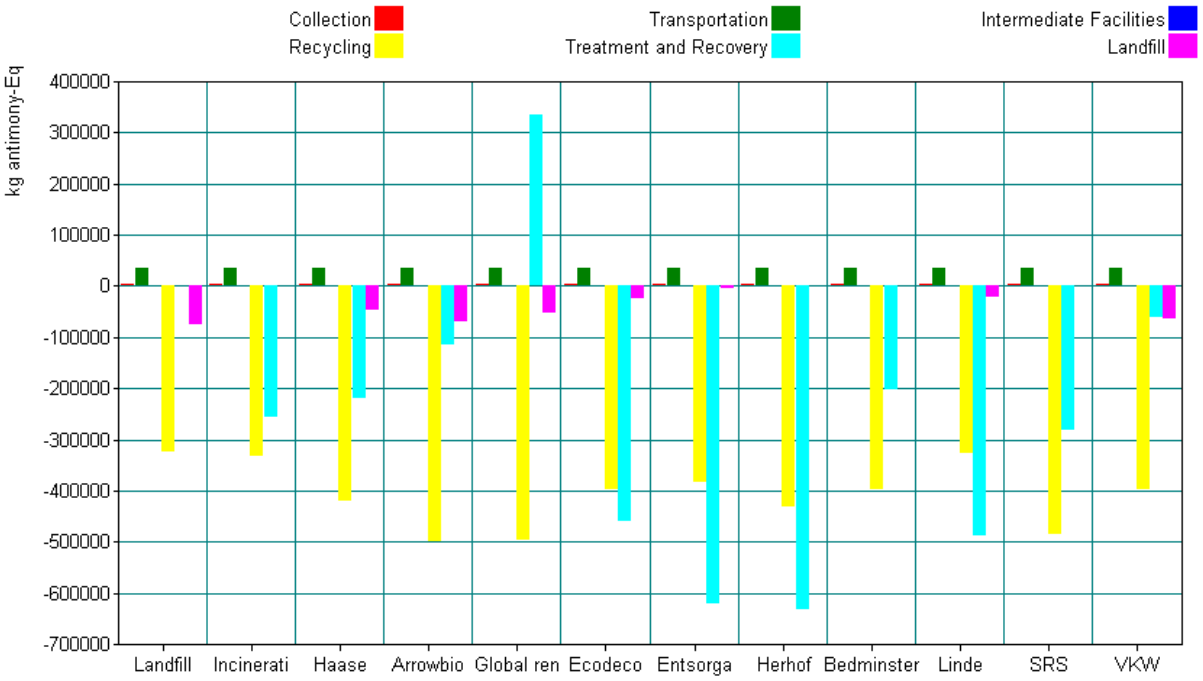


Figure 6: Abiotic resource depletion impacts by process

Figure 6 shows the resource depletion impacts of each scenario, broken down by process. Tables detailing impacts by resource are in Appendix B. Recycling again was similar for landfill, incineration and the Linde process. Processes with high levels of recycling, Global Renewables and SRS again had the greatest reduction in resource depletion; however, the Arrowbio process is also at a similar level. The Arrowbio process has a large amount of plastics recycling compared to the other processes, which might offset the use of oil in virgin plastic production preserving this precious resource. Although it does not necessarily take into account the quality of the recycling and thus the true replacement value of plastics. As stated in the assumptions, all recycling processes were idealised.

The treatment and recovery processes dominate the impacts for this category. The greatest reduction in resource depletion is for the Herhof and Entsorga processes, which produce the greatest amounts of RDF. Therefore the use of this fuel source to offset energy production from coal, oil and gas dominates. The worst treatment and recovery impacts are from the Global Renewables process, which, as explained before, has a very energy intensive separation process to maximise production of recyclables. Although it has some AD, its main

focus is on separating out recyclables, which makes the overall process quite energy intensive, giving a net increase in impacts for this category.

Interestingly residual waste to landfill shows the greatest benefit for this category. This can be attributed to the fact that carbon-based products such as plastics are being sequestered in the landfill and could theoretically be accessed for further use at a later date, while thermal processes will turn these into carbon dioxide and water, irreversibly. The generation of electricity from landfill gas would also be greatest for this scenario, giving an offset benefit from the production of electricity from fossil fuels. The other MBT processes which show a significant benefit for this category are the five which produced stabilite, which is landfilled therefore achieving similar advantages, although the ability to generate electricity from the gas generated in these landfills is controversial, as explained in the previous category. The Ecodeco process also shows quite a large recycling benefit, this process produced mainly RDF, however, it also had around 40% rejects which were sent to landfill.

Human toxicity

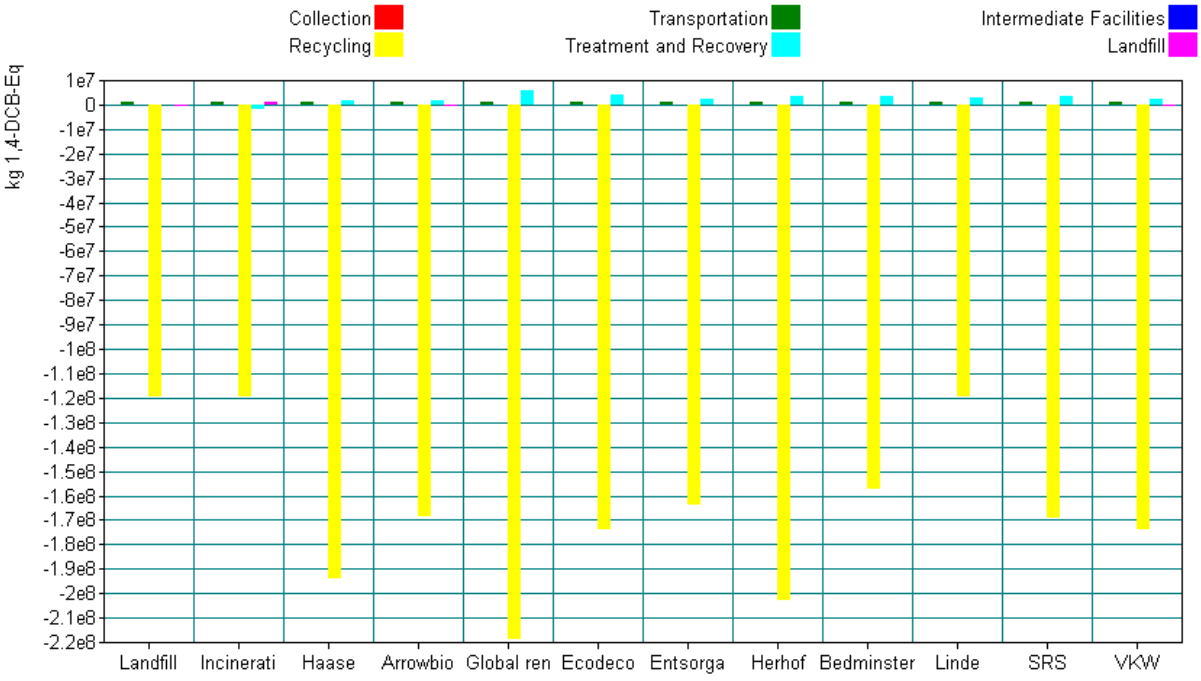


Figure 7: Human toxicity impacts by process

Figure 7 shows the human toxicity impacts by process. The results are overwhelmingly dominated by the recycling category. Again residuals-to-landfill provides a baseline, with

residuals-to-incineration and the Linde process having approximately the same impact. All other processes show an improvement over the baseline, due to their higher levels of recycling, with the Global Renewables process achieving the greatest benefit.

The treatment and recovery impacts are greater than zero for all of the MBT processes, while only being negative for incineration. This is an interesting result as anti-incineration pressure groups, who favour the use of MBT often cite human health impacts as one of the main reasons for avoiding incinerators (UKWIN, 2010). In fact the worst impacts appear to be caused by the Global Renewables process, which produces no RDF. Biological treatment of mixed wastes allow for release of pollutants into all three media, air, soil and water, while the incineration only allows emissions to air. The air pollution control regulations which apply to incinerator, through the Waste Incineration Directive (Parliament & Council of the European Union, 2000b) requires harmful substances to be captured in the pollution control filters creating an ash for disposal. The model does not allow for spatial considerations and the closeness of receptors to composting facilities must be taken into account, therefore the location of these near to populated areas would be controversial and require significant controls to be in place. However, locating them away from public places might lead to higher negative impacts in other categories due to the increased transport required. As explained, this is beyond the boundary of this project, but would be an important area of further research.

The landfilling category appears relatively insignificant across all processes. The highest impacts are from incineration, due to the fly ash collected which is landfilled. This would open up a pathway to human receptors through leaching into waterways, but again closeness to relevant receptors needs to be accounted for. It is likely that a hazardous waste landfill would be located further away from receptors than an MBT facility.

Freshwater eco-toxicity

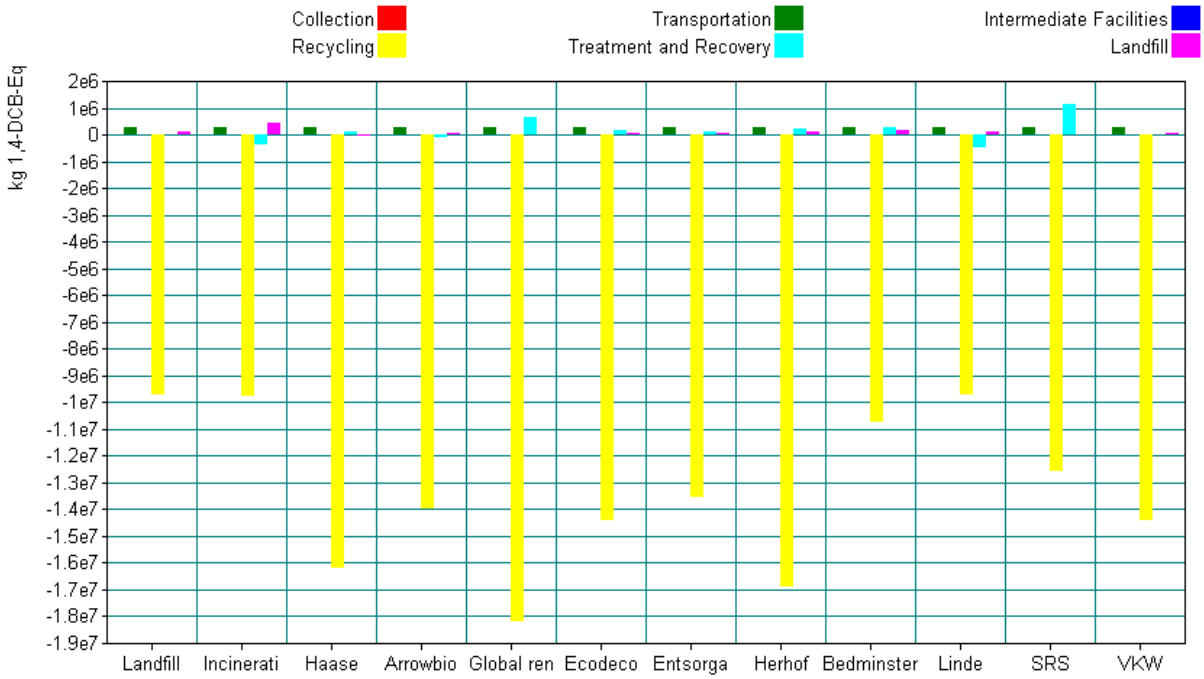


Figure 8: Freshwater ecotoxicity impacts by process

Figure 8 shows the breakdown by process of freshwater ecotoxicity impacts. Similar to human toxicity, the overwhelming influence comes from recycling. The different categories are similar to the previous category, as both are defined in terms of the same parameter.

Two of the worst processes in terms of treatment and recovery appear to be SRS and Bedminster, both of which produce low grade compost for application to land. The risk of leaching into ground water or runoff into surface water from application to land is obviously quite high. It is important to note however, that this would be spatially dependent, for example if it were applied to land that was not close to any freshwater sources, the risk of impact would be significantly reduced and this must be taken into consideration before deciding on which processes are appropriate. The SRS process appears much worse than Bedminster, even though Bedminster produces more compost. However, Bedminster uses AD as opposed to composting, the former is an enclosed process, with greater emissions controls. Global Renewables is also one of the worst performing processes for treatment and recovery. The high level recycling this process achieves comes at the expense of energy intensive separation techniques, and a significant amount is landfilled as stabilite, these two

factors have the potential to contribute to freshwater ecotoxicity, in the proximity of relevant receptors.

As with human toxicity, landfill impacts for incineration are the most significant, due to the hazardous air pollution control residues. Again proximity of a landfill to a waterway is not accounted for in the model, and must be taken into consideration in conjunction with these results.

Acidification

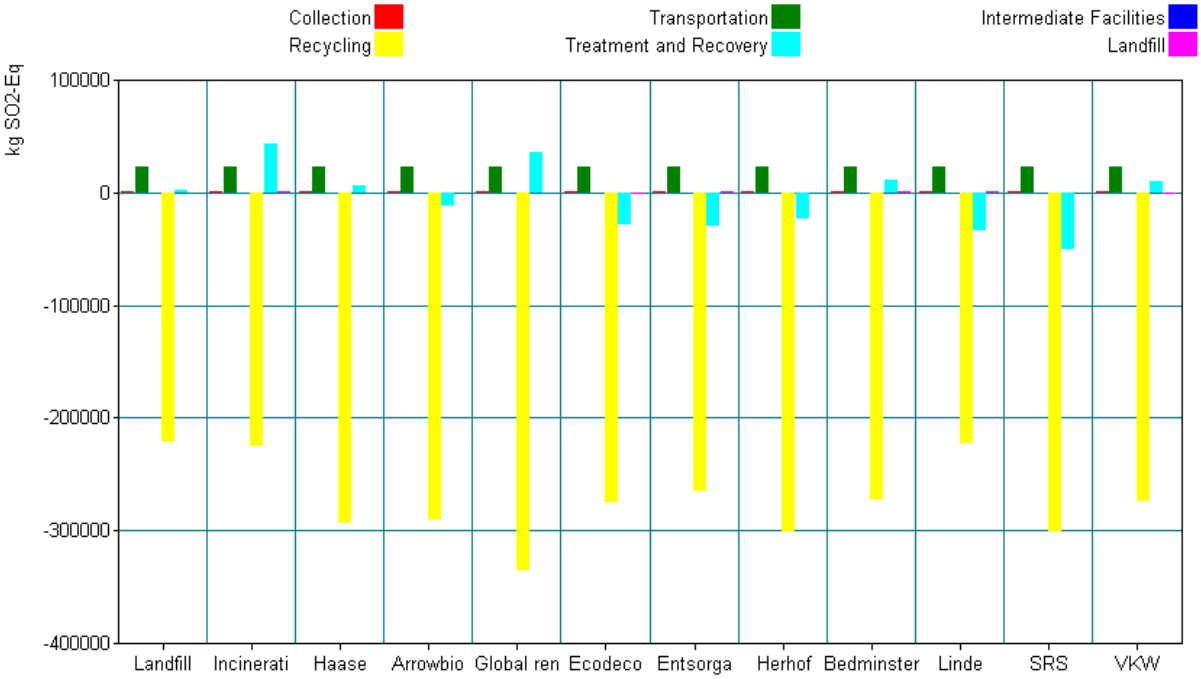


Figure 9: Acidification impacts by process

Figure 9 shows the acidification impacts broken down by process. Again recycling dominates, with residuals to landfill, residuals to incineration and the Linde process providing the baseline. All other processes show an improvement, due to the offset. Again the Global Renewables process appears to have the greatest benefit.

The greatest environmental burden in the treatment and recovery category can be seen to come from incineration, due to the release of oxides of nitrogen NO_X, a product of combustion. The Global Renewables process appears to have the next worst impact, most likely due to energy intensity of the separation of recyclables. Although composting allows for release of acidifying chemicals such as ammonia and NO_X through nitrification and

denitrification, the same impact is not seen from these, indicating it is more likely to be due to the energy intensive separation techniques employed at Global Renewables and combustion of the methane produced during anaerobic digestion. The SRS process, which employs composting as the biological part of its treatment, seemed to show the greatest benefit of all the processes in this impact category. The exception was the Arrowbio, AD process which gave a net burden, while with the exception of VKW, the processes that employed composting, had a net benefit. The Arrowbio process produces no RDF, therefore would have a reduction compared to other categories, due to no further combustion.

Landfill impacts are in general insignificant in this category. The main pollutant from landfills would be H_2S, however, in general this is found in trace levels within landfill gas.

Eutrophication

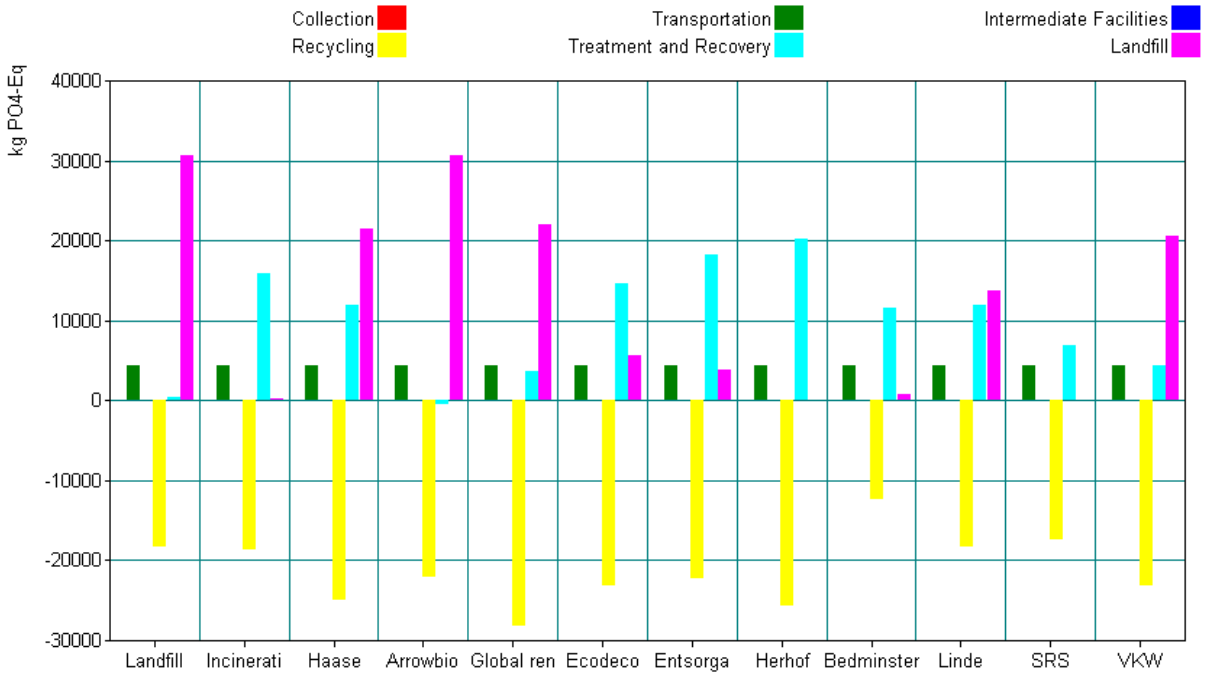


Figure 10: Eutrophication impacts by process

Figure 10 shows the breakdown by process of eutrophication impacts. In this case, the recycling processes dominate less than in the other impact categories. Residuals to landfill, residuals to incineration and the Linde process provide the baseline. For the first time two processes, SRS and Bedminster, appeared to perform worse than the baseline. Both of these processes produce low grade compost for application to land, a significant pathway for

eutrophying pollutants to reach receptors. However, proximity to relevant receptors is not accounted for in the model and must be taken into consideration in conjunction with these results. All other processes followed similar patterns to the previous categories, with the Global Renewables process offering the greatest benefit.

Treatment and recovery showed a net burden in this category for all processes except Arrowbio. Composting can contribute significantly to this category due to nitrification and denitrification. NO_X from the combustion process also contributes to this impact category via its potential for deposition. Although, before deciding on the significance of this category it would be necessary to complement these results with an atmospheric dispersion model, and then consider the sensitivity of receptors.

A significant burden on this impact category is noted from residuals to landfill, as well as the five MBT processes which produce stabilite. Biodegradable wastes in landfill provide a significant route for this waste type to enter the environment. Again proximity to receptors should be taken into account in conjunction with these results. The landfill directive has requirements for the siting of landfills to ensure they do not pose a risk to ground water (Environment Agency, 2010a).

Normalisation

In order to compare the magnitude of the different impact categories, a normalisation factor is defined in the model called 'Euro person equivalent'. This value is defined as the annual impacts caused by an average European person. This obviously leads to some controversy as a 'European person' is highly variable depending on both the country and the lifestyle of the person considered. Indeed there appears to be no scientific basis for the definition of these types of normalisation values based on spatial and temporal scales, and it appears to simply be convenient for consistency in reporting of data with other studies (Bare, 2010). The benefit of the value is that it allows comparison between impact categories. Figure 11 shows the normalised values for all waste treatment methods for each impact category. In general impacts are below zero, indicating a positive environmental performance. Eutrophication has the greatest burden, which is similar for all scenarios. Second worst impacts arise from GHG emissions, followed by acidification, with human and

freshwater eco-toxicity showing the lowest impacts in general. Abiotic resource depletion has the greatest variance between scenarios.

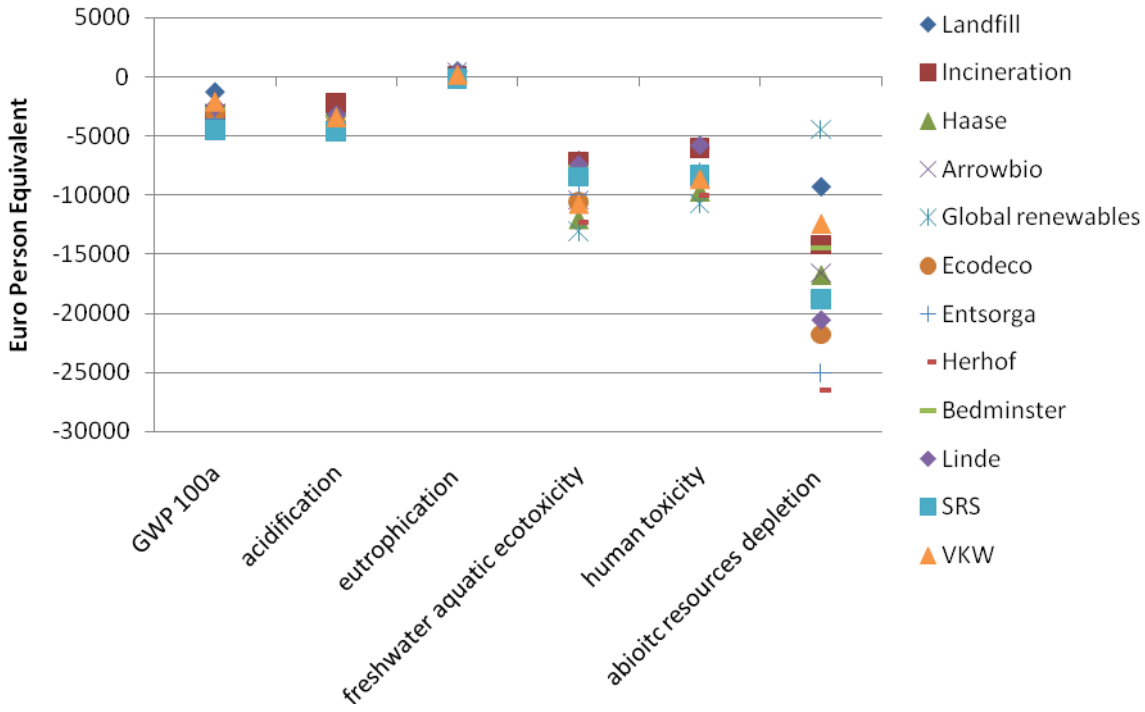


Figure 11: Normalised impacts from all scenarios

3.5. Conclusion and suggestions for future work

In this chapter the overall aim of the thesis, to compare waste management systems for biodegradable municipal waste, has been addressed through the use of LCA. The MBT process of Global Renewables appeared to show the greatest benefits due to recycling, across all categories. Treatment and recovery impacts from different categories were highly varied. In general GHG emissions and resource depletion tended to show a net benefit for processes with energy recovery. The electricity mix offset by these values was UK 2010, which is largely generated from coal, oil and gas. Variation in the benefits with different electricity mixes will be investigated in the following chapter.

4. Varying the electricity mix

4.1. Introduction

Electricity is arguably the most important commodity in modern life. It affects nearly every aspect of daily life and its use is growing annually not just in line with population growth, but also with expansion to rural areas. Providing fuel to sustain increasing electricity demand, in an economically stable way that minimises environmental harm, is one of the biggest challenges facing governments today. Currently, in the UK over 70% of electricity is supplied by fossil fuels, around 20% from nuclear and less than 10% from renewable sources. The import rate of fossil fuels is increasing, coal for instance is the main fossil resource found in the UK, but indigenous supplies have decreased from 65% in 1998 to only 27% in 2006 (BERR, 2007) and are still only supplying around one third (DECC, 2009c), while approximately 46% is sourced from Russia. Worldwide reserves of fossil fuel are believed to be dwindling although there is disagreement about the precise amount there is some consensus that reserves are finite (Shafiee and Topal, 2009, Asif and Muneer, 2007). Further to this, concerns about the political stability of relations with countries that have the largest fossil fuel reserves are promoting an interest in increasing home-produced fuel sources to ensure a secure energy future in terms of a constant supply at reasonable cost. Diversifying the fuels that supply electricity, rather than relying on one or two sources will also increase energy security, avoiding incidents such as the oil crisis of the 1970s. The UK is well placed for supplies of renewable sources especially wind, biomass, and tidal power. Exploiting energy from waste will also make a contribution.

The UK Government has made a legally binding commitment to reduce GHG emissions to 80% of 1990 levels by 2050 (DECC, 2008). Energy generation accounts for approximately 85% of UK GHG emissions (Baggott et al., 2005) and is therefore a key area for emissions reductions. Coal-fired power stations, which currently provide around one third of the UK's electricity, produce more CO_2 per kWh than any other fossil fuel. The US Energy Information Agency estimates that coal emits 0.963 $kgCO_2$ per kWh, while oil emits 0.881 $kgCO_2$ per kWh and gas emits 0.569 $kgCO_2$ per kWh (EIA, 2011). The European Commission's research project on the externalities of energy (ExternE) gives a range of emissions factors for coal from 0.499 to 1.073 kg per kWh depending on the technology

employed (ETSU and IER, 1995). The expansion of coal use would therefore breach the commitment, until the use of carbon capture and storage becomes commercially viable (DECC, 2010a). Public awareness of the situation has increased the difficulty of expanding the use of coal as highlighted in 2008 when six Greenpeace activists who broke into the Kingsnorth power station and shut down operation were acquitted by a jury, under the 1971 Criminal damage act, which states that 'criminal damage is justified, where it prevents even greater damage'(Vidal, 2008).

The combination of increasing energy security and reducing greenhouse gas emissions led The European Union to publish a directive promoting the use of renewable energy sources, committing member states to achieving an overall 20% of energy from renewables by 2020 (European Parliament and Council, 2009). The directive requires the UK to source 15% of its energy from renewables by 2020 (DECC, 2009c). The UK intends to distribute this so that electricity generation accounts for 30%, heat 12% and transport 10%. However, this alone will not be enough to achieve the required CO_2 emissions reduction; therefore recently, expansion of nuclear power has also been given significant government support. It has been made clear this will not be financial but rather support in pushing through planning applications. The push for nuclear currently only applies to England, whereas Scotland and Wales are intending to avoid increasing their nuclear supplies, and invest more heavily in renewables (Huhne, 2010). Therefore the future baseline electricity fuel mix in the UK is almost certain to be higher in renewables coupled with a significant amount of nuclear in England, while the use of fossil fuels is expected to decrease, until the use of carbon capture and storage becomes commercially viable.

Wind energy is expected to make the greatest contribution to renewable electricity, however, energy from waste could also make a significant contribution. In 2009 approximately 20% of UK renewable energy was sourced from landfill gas, however, supplies of this will decline rapidly as the landfill directive biodegradable waste diversion targets are implemented (Council of the European Union, 1999). Other energy from waste techniques will therefore replace this, including incineration, anaerobic digestion, SRF and advanced thermal treatments (ATTs), gasification and pyrolysis. As explained in the introduction, ATTs may not be commercially viable in time to meet renewable targets. These also require a homogeneous fuel, such as SRF, and therefore would need to be developed in

conjunction with an MBT or MHT facility. Therefore they are not considered in this assessment.

The UK government introduced renewable obligation certificates (ROCs) in order to implement the renewable energy strategy. These are awarded on a per MWh basis, depending on the renewable technology employed. For example landfill gas receives 0.25 ROCs/MWh, while anaerobic digestion and ATTs attracts 2 ROCs/MWh. Generation of electricity from incineration of mixed waste is not eligible for ROCs unless CHP is used. Currently electricity suppliers are required to have 11.1ROCs/100 MWh of energy generated in England, Scotland and Wales, and 4.27 ROCs/100 MWh in Northern Ireland. Suppliers who fail to produce the required number of ROCs must pay a fee per missing ROC into a fund which is paid back on a pro-rata basis to suppliers which have presented the required number of ROCs (Of-gem, 2010).

In the LCA presented in Chapter 3 the electricity supply was based on UK 2010 case which, as can be seen in Table 7, is largely fossil fuel based. Therefore energy from waste showed a significant environmental benefit. Due to the legislation outlined above, this is almost certain to alter significantly in the next 5-10 years. In order to take this into consideration the modelling was repeated with 3 different electricity fuel mixes, also shown in Table 7. A high renewables scenario based on Norway 2002, and 2 high nuclear scenarios, France and Lithuania, 2002. The energy efficiency of the incineration process is also considered, by varying the type of incinerator from the CHP used in the original assessment, to one that generates only power. This addresses the sixth objective of this thesis.

A brief review of the way environmental impacts of electricity generation are calculated for LCA and a description of electricity generation calculations in WRATE is presented prior to the modelling results.

4.2.LCA of energy

Inventories for LCAs usually contain a set of energy generation options that can be used in different processes, including those to treat municipal solid waste. The inventories are based on LCAs conducted into energy generation, starting at upstream emissions, i.e. materials required to build the plant, extracting the fuel from nature; operational emissions, and upstream emissions involved in decommissioning. Energy generation plants can be built

using different techniques and materials, or materials derived from different processes; impacts during the operational phase depend on emissions control technologies; and decommissioning varies significantly between countries. Therefore in order to provide generic environmental impact values for electricity use, in a convenient 'per MWh' form, a certain level of assumptions must be made that may not be applicable to the task undertaken. This only really becomes a problem when the energy generation is being addressed specifically. Two approaches to calculating impacts are commonly found in the literature. Top down approaches that consider inputs and outputs at each process and the links between them, and bottom up approaches which assess the impacts from each material. The former uses average values, where as in the latter an inventory is established for each material. Some studies use a combination of the two techniques applying the top down approach to secondary materials and the more detailed analysis to the materials of most interest (Odeh and Cockerill, 2008, Weisser, 2007). These are established in the system boundaries.

Reviews of the large number of LCAs specifically assessing electricity production from different fuels are available in the literature. These often focus on a specific fuel type for example Sovacool (2008) summarises results from 103 separate studies on nuclear fuels; Odeh and Cockerill (2008) focussed on coal, and Varun et al. (2009) reviewed renewable energy technologies. However, all of these studies only compile inventories for greenhouse gas emissions, because it is politically the most pressing impact for governments to tackle at the moment. Data on other environmental impacts appears to be exclusive to the development of life cycle assessment inventories, such as ecoinvent (Dones et al., 2005).

Fossil fuels

Even though coal currently supplies 33% of the UKs energy, it produces 50% of carbon emissions from the energy generation sector (Odeh and Cockerill, 2008). The use of CCS could potentially reduce emissions from coal power stations by 80-90% depending on the specific technology employed (Weisser, 2007), however, it is important to consider that there would be a subsequent increase in the amount of fuel used per kWh generated, increasing costs and upstream emissions (Weisser, 2007). Analysis of the system is essential to ensure that using this relatively cheap fuel will still be economically viable. Odeh and Cockerill (2008) conclude that the decision of the best abatement method for GHG emissions from energy generation will be a trade-off between coal plants with CCS, cheap fuel with

expensive technology, and gas more expensive fuel with cheaper technology. CCS will reduce direct process emissions, making indirect emissions more significant. Fossil fuel extraction, for example, often occurs in less developed countries with little or no environmental regulation, thus the emissions from this process, which could become up to 25% of total life cycle, would not be accounted for.

Nuclear

Emissions from nuclear are very low during normal operation and are not especially significant upstream. However, the downstream emissions can be very significant. Energy use during decommissioning has been estimated to be twice that of construction (Sovacool, 2008). It has also been noted that while the operational lifetime of a nuclear plant is expected to be 40yrs (although only approximately 24 of these will be operating at full power) the decommissioning phase can take up to 60 years. Published life cycle assessments tend to assume a life time, which is not reflected in reality, (i.e. assume full operation for 40 years, which is not achieved in practice.)

Renewables

Wind energy is expected to be the largest source of renewable energy in the UK, and globally it is one of the fastest growing energy sources, at approximately 34% per annum. It has one of the lowest emissions calculations of all available technologies, however, the variability of wind sources and the fact that the wind does not blow constantly or at a consistent rate, means it can only account for a maximum of around 20% of electricity supply, without affecting reliability (Lenzen, 2010, Varun et al., 2009).

Worldwide the most common renewable fuel is hydropower. There are no emissions during operations and the downstream emissions are considered to be insignificant. The upstream emissions can be significant, particularly where reservoirs are purpose-built, which is the case in over 90% of dams, as the process involves clearing an area of land of vegetation and flooding it (Lenzen, 2010). The clearing contributes to GHGs through decomposition of the vegetation, plus the soils will degrade more rapidly underwater with both aerobic and anaerobic conditions leading to production of CO_2 and CH_4. While run-of-river systems do not have these upstream impacts, they are often subject to seasonal fluctuations, requiring a backup supply of energy and this must also be included in the inventory to provide realistic

environmental impact figures (Varun et al., 2009). Finding suitable land space to expand hydroelectricity generation can also be controversial. For example, Endesa the electrical company in Chile intends to establish five dams in the Patagonian region. This endeavour would displace local communities, and destroy the unique native ecosystem (Wharton School, 2008).

The use of tidal power was also intended to form a significant part of the UK fuel mix, based in the Severn estuary, but a feasibility study has indicated that this is not an economically viable method of energy generation, although did not rule out the possibility of employing it in the future (DECC, 2010b).

Biomass including biodegradable waste, currently makes the greatest contribution to electricity generation from renewable sources, and is expected to continue to form a significant part of the UKs fuel mix (DECC, 2009a).

Treatment of energy impacts in WRATE

WRATE uses the ecoinvent database to calculate the impact from energy generation processes. Baseline fuels supply a constant rate of electricity. Marginal fuels provide extra electricity when demand exceeds the baseload. Energy from waste is offset against the marginal fuel mix. Therefore in each waste management process, the burdens associated with the use of 1MJ of electricity are calculated using the baseline fuel mix while the production of 1MJ of electricity is calculated using the marginal fuel mix. Equation 1 indicates the calculation in WRATE, which is the same for use and production, except that b_r is negative when calculating the offset. The 1MJ is calculated at the end user, taking account of transmission losses and generating efficiencies:

$$1/(1-t)\ \Sigma b_r p_r / e_r \qquad \text{(Equation 1)}$$

b_r is the value of the same burden associated with 1MJ of the rth energy source
p_r is the proportion of the energy in the mix that comes from the rth energy source
e_r is the generating efficiency associated with the rth energy source
t is the medium voltage transmission loss as a proportion of distance
(Environment Agency, 2007)

4.3. Methodology

Table 7: Electricity mix data for Norway, France, Lithuania and the UK (Environment Agency, 2007)

	UK Baseline fuel mix (%)	Generating efficiencies	Marginal fuel mix (%)	**Norway** Baseline fuel mix (%)	Generating efficiencies	Marginal fuel mix (%)
Coal	34.4	35.7	46.6	0.2	29.1	0.2
Oil	0.3	33.1	0.8	0.0	27.6	0.0
Gas	3.4	34.9	3.3	0.2	34.9	0.2
Gas CCGT	34.3	47.6	49.3	0.0	46.6	0.0
Nuclear	18.1	38.6	0.0	0.0	27.7	0.0
Waste	0.2	20.6	0.0	0.1	25.4	0.1
Thermal other	0.8	18.7	0.0	0.0	29.1	0.0
Renewables thermal	2.3	25.8	0.0	0.2	18.1	0.2
Solar PV	0.0	15.5	0.0	0.0	15.5	0.0
Wind	4.9	25.0	0.0	0.0	25.0	0.0
Tidal	0.0	82.0	0.0	0.0	82.0	0.0
Wave	0.0	82.0	0.0	0.0	82.0	0.0
Hydro	1.3	82.0	0.0	99.3	82.0	99.3
Geothermal	0.0	82.0	0.0	0.0	82.0	0.0
Renewable other	0.0	82.0	0.0	0.0	82.0	0.0
	France Baseline fuel mix (%)	Generating efficiencies	Marginal fuel mix (%)	**Lithuania** Baseline fuel mix (%)	Generating efficiencies	Marginal fuel mix (%)
Coal	4.5	29.1	20.4	0.0	29.1	0.0
Oil	0.8	27.6	3.7	4.2	27.6	20.6
Gas	4.2	34.9	19.1	10.8	34.9	53.7
Gas CCGT	0.0	46.6	0.0	0.0	46.6	0.0
Nuclear	78.0	27.7	0.0	79.8	27.7	0.0
Waste	0.3	25.4	1.5	0.0	25.4	0.0
Thermal other	0.0	29.1	0.0	0.0	29.1	0.0
Renewables thermal	0.3	18.1	1.4	0.0	18.1	0.1
Solar PV	0.0	15.5	0.0	0.0	15.5	0.0
Wind	0.0	25.0	0.0	0.0	25.0	0.0
Tidal	0.0	82.0	0.0	0.0	82.0	0.0
Wave	0.0	82.0	0.0	0.0	82.0	0.0
Hydro	11.8	82.0	53.4	4.4	82.0	21.8
Geothermal	0.0	82.0	0.0	0.0	82.0	0.0
Renewable other	0.1	82.0	0.7	0.8	82.0	3.9

NB: Baseline fuels provide a constant supply of electricity.
Marginal fuels provide electricity when demand exceeds the base load.

Table 7 shows the four cases used in this study: The UK, which is the base case used in the original modelling, Norway, an example of a high renewables supply, with over 99% of power generated from hydro, France, a high nuclear baseline, with high renewables marginal and Lithuania a high nuclear baseline with high fossil fuel marginal mix.

All input data to the model was the same as that presented in the methodology of Chapter 3, except for the electricity fuel mix. Table 8 repeats the table in Chapter 3 showing the main outputs of each MBT process, included here for ease of reference. More detailed tables of these processes can be found in Appendix A.

The percentage difference in impacts between the UK2010 case and each of the other three cases were calculated and are presented graphically in the results section.

Table 8: Outputs from MBT processes

MBT process	Biological treatment	Total output (t)	% product	% RDF	% stabilite	% recycled
Haase	AD	9.5E+06	21.3	15.5	78.7	1.4
Arrowbio	AD	1.3E+07	50.8	0.0	35.2	15.6
Global Renewables	AD + compost	1.2E+07	52.3	0.0	32.7	19.7
Ecodeco	Biodrying	1.1E+07	63.8	50.9	0.0	4.1
Entsorga	Compost(biodrying)	1.1E+07	76.0	66.7	0.0	0.8
Herhof	Compost(biodrying)	1.0E+07	94.1	73.7	0.0	13.4
Bedminster	AD + compost	9.8E+06	79.6	25.3	0.0	1.0
Linde	Compost	1.3E+07	60.9	45.0	30.9	0.1
SRS	Compost	1.1E+07	100.0	33.7	0.0	30.4
VKW	Compost	1.1E+07	97.5	6.6	86.0	1.9

4.4. Results and discussion

Norwegian electricity mix – a high renewables scenario

The first comparison was between the UK 2010 and Norway 2002 fuel mixes. Norway sources over 99% of its energy from renewable hydropower (Table 7) in both the baseline and marginal fuel supply. Figure 12 shows the percentage difference in characterisation value for the 6 impact categories in WRATE. It can be seen that GHG emissions from landfill and

incineration are over 50% worse with the Norway 2002 case, compared to the UK2010. This was expected as both landfill and incineration can be used for energy generation. When replacing the use of fossil fuels, saved emissions from fossil fuel burning gives these processes a significant net environmental benefit. Hydropower on the other hand, has no GHG emissions during operation, negligible downstream emissions, with upstream emissions making the only significant contribution. Estimates from the literature show that even with worst case scenario assumptions, the emissions from hydropower would be 0.237 kg CO_2 equivalents per kWh, (Varun et al., 2009) which is less than half that of gas, the lowest emitting fossil fuel source. Therefore replacing the marginal fuel mix with energy from waste, will not lead to a significant benefit. Several of the MBT processes also show significant increases in GHGs, including Haase, Arrowbio, Global renewables and VKW, all these processes send significant amounts of their outputs to landfill after biological treatment. The partially degraded outputs from MBT, labelled Stabilite in WRATE, are modelled in a way similar to untreated BMW in terms of gas generation, therefore would have a similar result to landfill. The difference is simply due to the fact that less mass is landfilled. The MBT processes Bedminster and Herhof, and to a lesser extent Entsorga, Linde and SRS show the opposite trend with an increased environmental benefit with the Norwegian mix. These processes offer little opportunity for energy recovery, but are net energy users. Calculation of electricity use from the Norwegian baseline would have very insignificant greenhouse gas emissions, compared to the UK2010 baseline which is mostly fossil fuels. This highlights the influence that fuel for electricity has on the choice of a waste management system, when basing the decision on GHGs.

Resource depletion shows a less significant variation to GHG emissions, although the pattern was similar in that the same processes showed improvement/deterioration as in the previous category. The depletion of fossil fuels is one of the main considerations in this impact category, therefore generating energy from waste, to replace energy from fossil fuels produces a significant environmental benefit, compared to replacing renewable hydropower, which does not deplete abiotic resources during operation. Processes that are net users of energy on the other hand, have a lower impact on resource depletion with a renewable baseline fuel supply, compared to a fossil fuel baseline.

The variation in acidification impacts is less significant than in the two previous categories. The most significant change was in the incineration, showing an approximately 20% increase in emissions with the Norwegian case. The combustion of fossil fuels produces high levels of NO_X gases, which are precursors of nitric acid. Replacing fossil fuel with energy from waste would therefore reduce emissions of acidifying pollutants. The incineration process would also produce NO_X, whereas hydroelectricity generation does not lead to the formation of gases during operation, and would only have insignificant emissions during the upstream process. Landfill and some of the MBT processes, especially those which produce a lot of stabilite for landfilling, also show increased impacts with the Norwegian case, due to their ability to offset the use of fossil fuels in the UK scenario. Other processes which produce a lot of stabilite, use rather than produce energy and therefore do not show a significant change.

Both of the toxicity categories show insignificant variation, being less than 1% for most of the scenarios, except incineration and Arrowbio. Again the incineration scenario can be attributed to its significant energy production. The Arrowbio process uses AD, coupled with a high level of stabilite to landfill, giving two opportunities to recover energy from waste during the process.

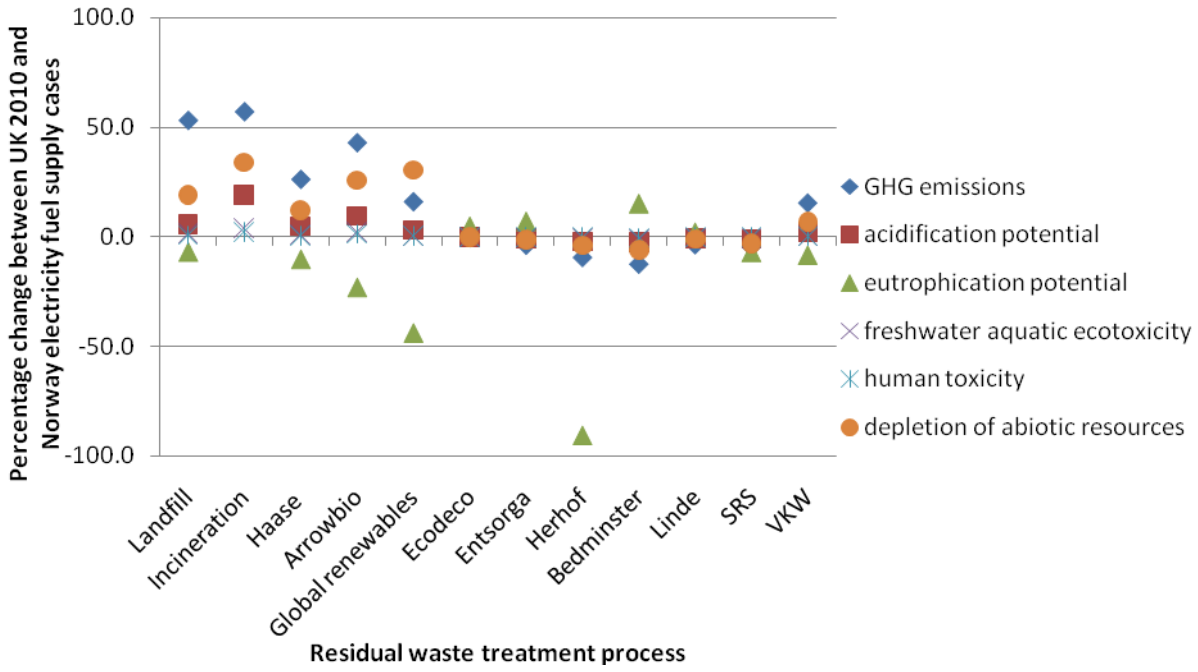


Figure 12: Comparison of impacts with Norwegian electricity mix

Eutrophication showed the most significant variation especially for incineration which was beyond the axes presented at -164.5% and Herhof, however, unlike the other impact categories the benefit of using energy from waste in the Norwegian case showed a significant increase in impacts compared to UK 2010. Hydropower leads to long hydraulic residence times and high particle trapping efficiency of reservoirs providing ideal conditions for eutrophication to occur, especially high levels of nutrients in sunlight, with no flushing (Whittaker et al., 2006). Therefore replacing hydropower with energy from waste to generate electricity actually leads to a greater reduction in eutrophication impacts than replacing fossil fuels. In the previous impact categories the use of landfill gas for electricity production also led to significant improvements, however, landfills in this category do not have the same benefit, for although they produce electricity, they also provide significant pathways to relevant receptors including leaching, runoff and atmospheric deposition. Although incineration leaves a residue which requires landfilling, the WRATE modelling results indicate that the substances that contribute to eutrophication, especially ammonia, are not present in this. Looking at the detailed composition of APC residue in WRATE, only trace amounts of hazardous substances are present.

For the Bedminster process the eutrophication impacts are significantly decreased in the Norwegian 2002 case compared to UK 2010. The process produces a significant amount of

compost-like outputs which are applied to land as a soil conditioner, which significantly increases the risk of pollutants reaching relevant receptors through runoff, as unlike landfill, the CLOs are spread on top of the soil, with fewer controls in place to prevent runoff. It should be noted however, that eutrophication impacts are very dependent on the sensitivity of receptors. For example in Scandinavian countries a deposition of 100 eq per hectare per year shows a negative effect, while ecosystems in parts of Germany and the Netherlands can withstand deposition rates of 2000 eq per hectare per year before showing impacts (Consultants, 2004). Legislation relating to application of fertiliser products to land is thus regulated in terms of proximity to relevant receptors. Addition of significant amounts of fertiliser on or close to areas particularly sensitive to eutrophication impacts is restricted. Therefore even though the results of this assessment show a negative result, the geographical location should be considered in conjunction with these results.

Hydropower produces less greenhouse gas emissions, acidifying pollutants and, to a lesser extent, toxic pollutants and uses few abiotic resources compared to fossil fuels, however, it has the potential to produce conditions much more conducive to eutrophication. Therefore using energy from waste to replace hydropower shows an increased environmental burden compared with replacing the use of fossil fuels, in all impacts categories except for eutrophication. In the UK, the current mix of renewables is over 50% from biomass, followed by wind and only a small amount of hydropower. Plans indicate that increased renewables will focus on wind energy, rather than hydro, which does not have the same impact on eutrophication (Lenzen, 2010, DECC, 2009a). Therefore it is important in deciding on future waste management systems that the likely changes to the fuel supply for electricity generation are taken into consideration.

The UK is unlikely to increase its renewable contribution above the 20% it is committed to in the current regulations, as the government has recently given support to expansion of nuclear fuel use (Huhne, 2010). The following scenarios investigate high nuclear fuel use.

French Electricity Mix

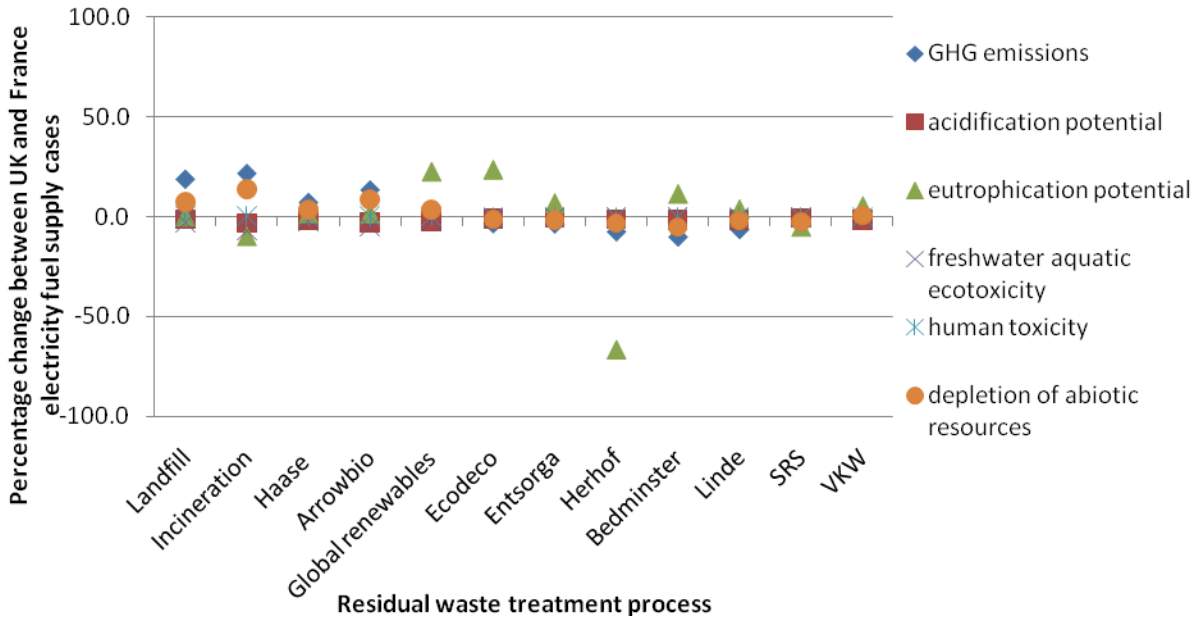


Figure 13: Percentage change in impacts with a French electricity mix

The UK government's recent support for increased nuclear energy indicates that it is likely to be a significant part of the UKs baseline fuel in the future. Nuclear power cannot form part of the marginal fuel mix as it cannot be adjusted, but must run at constant power. In order to consider a fuel supply with significant nuclear in the baseline and significant renewables in the marginal mix, France 2002 was used. Table 7 shows the baseline mix is approximately 80% nuclear, 12% renewables and less than 10% fossil fuels. The marginal fuel mix for France is over 50% renewable hydropower, with the remainder split between the three main fossil fuels, coal, oil and gas.

Figure 13 shows the percentage change in impacts between the UK 2010 and French 2002 cases for all 12 scenarios. The variations in GHG emissions impacts are similar to the Norwegian ones, for waste management processes that produce a lot of energy. The burdens associated with the use of 1MJ energy are much lower, as nuclear energy has much lower emissions than fossil fuels. The production of 1MJ would also be much lower than for the UK scenario, as over 50% of the marginal fuel mix is hydropower, which, as explained above, has very low emissions. Similarly the MBT processes that are net energy users perform better in the French case. The differences are less significant than in the Norwegian case however, as while nuclear plants have almost zero GHG emissions during operation the

downstream and upstream impacts are much more significant than renewable energy plants, especially the downstream, as the decommissioning of nuclear facilities can exceed the operational lifetime (Sovacool, 2008).

The comparison in abiotic resource depletion shows a similar trend to GHG emissions, although the variation is less significant. The majority of the MBT processes show an insignificant variation.

Both the toxicity categories show insignificant variation, indicating that the release of these pollutants from electricity generation is insignificant and therefore there is little potential for offsetting these impacts through the use of energy from waste.

Replacing the French 2002 case with energy from waste shows a slight increase in acidification impacts, compared to replacing the UK2010 case. This result appears unexpected, as in the French case over 50% of the marginal fuel mix is from renewable hydropower, which would emit insignificant amounts of acidifying pollutants, while the UK 2010 is a mix of gas and coal. However, in the UK 2010 case, a combined cycle gas turbine is used, which would not emit significant amounts of acidifying pollutants, while the remainder of the French 2002 mix is made up of fossil fuels especially gas and coal as in the UK, however, the gas is burned in an open cycle gas turbine which would have very significant emissions compared to the combined cycle technology used in the UK.

Eutrophication impacts show a significant variation for many of the MBT scenarios, especially Herhof which shows a 67% improvement with nuclear over fossil fuel. While Global Renewables and Ecodeco are significantly worse, this appears to be related to emissions to air of ammonia and NO_X.

Lithuanian Fuel Mix

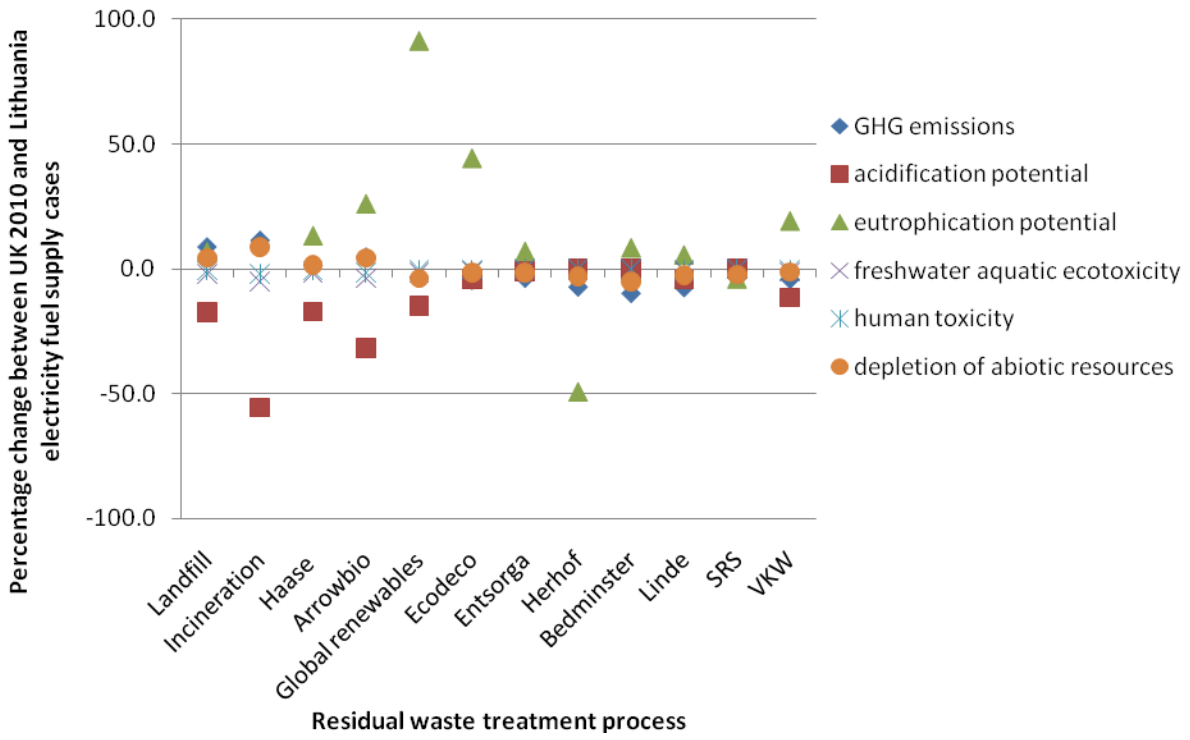


Figure 14: Lithuanian electricity mix

Figure 14 shows the percentage change in impacts between Lithuanian 2002 and UK 2010 fuel mixes. The change in GHG emissions vary similarly to the two previous scenarios, with scenarios that produce energy from waste having increased emissions in the Lithuanian case, compared to the UK, although the difference is much less significant. The resource depletion scenario is not significantly different, to the GHG emissions scenario. The two toxicity categories again show insignificant variation.

The acidification impacts are significantly increased when energy from waste replaces the Lithuanian fuel mix compared to the UK. Although the baseline fuel mix in Lithuania is mostly nuclear, which would have very low emissions of acidifying pollutants; the marginal fuel is over 50% gas, and uses open cycle gas technology which would lead to significant emissions of acidifying pollutants, especially SO_2, compared to the combined cycle gas turbine technology employed in the UK. Table 9 presents the pollutants that contribute to acidification, the third column shows the reduction in emissions when energy from waste produced in an incinerator replaces the electricity production from the marginal fuel mix in

the Lithuanian case, while the fourth column shows the same for the UK2010 case. As can be seen the most significant difference is in SO_2 emissions.

Table 9: Acidification pollutants from incineration

Substances	Unit	Lithuanian	UK 2010
Total	kg SO_2-Eq	-244673	-157240
Ammonia	kg SO_2-Eq	5543	5067
Nitrogen oxides (NO and NO_2 as NO_2)	kg SO_2-Eq	7921	16070
Sulphur dioxide	kg SO_2-Eq	-251777	-172018
Sulphur oxides (SO_2 and SO_3 as SO_2)	kg SO_2-Eq	-6359	-6359

Eutrophication again shows the most significant variation. In the case of incineration the value was off the scale of the graph, at 145%, while most of the MBT scenarios show a large improvement, except for Herhof, which has consistently shown significantly better performance in this category in all three cases presented. Looking at the breakdown of pollutants, the greatest contribution in the Herhof process appears to come from emission to air of ammonia and also NO_X. Global Renewables have the most significant variation in the other direction, which also seems to be related to change in NO_X emissions.

Normalised Impacts

The normalised impacts are shown in Figure 15. The difference in environmental impact with the different electricity fuel mixes is indicated by the space between the four different data points for each waste management scenario. Focusing on the incineration point, the red square, representing the Norwegian fuel mix, is closer to the environmental impacts of the landfill scenario, while the blue diamond, representing the UK2010 fuel mix is more negative indicating an increased environmental benefit. For all the MBT scenarios, the four data points are closer together than the incinerator scenario, indicating that the impact of varying the fuel mix is less significant. The Arrowbio scenario shows the largest variation, with the Norwegian point being having a more positive score, indicating a worse environmental performance than the other three electricity fuel mixes. This is likely to be due to the fact that this process produces energy through anaerobic digestion. In all scenarios it can be seen that the data points for France (green triangle) and Lithuania (purple cross) fall at approximately the same point, indicating the variation is not significant.

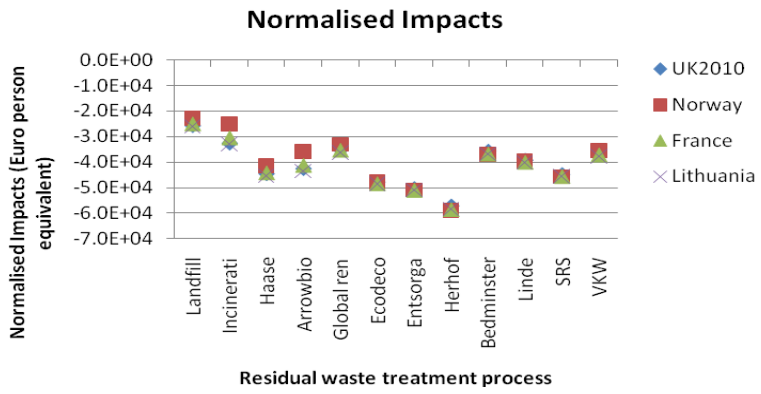


Figure 15: Normalised impacts with different electricity mixes

Incinerator Type

In this section, an incinerator that generates power only was modelled alongside the CHP incinerator considered in the previous section. The waste framework directive Annex II R1 footnote defines the efficiency requirements of an incinerator for municipal solid waste in order for it to be classified as a recovery operation, as opposed to disposal. Table 10 presents the overall impacts for each category for the two types of incinerator. The most significant variation is in the eutrophication category. Acidification is the next most significant result showing it to be 10.8% worse with the lower efficiency incinerator. The GHG emissions are reduced by 3.5% which is not that significant, especially when compared with the large increases seen in the case studies above. However, it is important to consider that while WRATE has quite sophisticated calculation of electricity benefit, it does not devote the same attention to waste heat, in the calculation of waste heat, WRATE offset against a gas combustion inventory with a thermal efficiency of 85%. Therefore the apparently insignificant results may be due to a limitation of the software.

Table 10: difference in impacts with lower efficiency incineration

Impact Assessment	Unit	CHP	Power only	% variation
GHG emissions	kg CO_2-Eq	-4.1E+07	-3.9E+07	3.5
acidification potential	kg SO_2-Eq	-157240	-140245	10.8
eutrophication potential	kg PO_4-Eq	2040	6754	231.1
freshwater aquatic ecotoxicity	kg 1,4-DCB-Eq	-9413203	-9569293	-1.7
human toxicity	kg 1,4-DCB-Eq	-1.2E+08	-1.1E+08	3.6
Resources depletion	kg antimony-Eq	-547983	-592583	-8.1

Table 10 indicates that increasing the efficiency of energy produced from an incinerator through combined heat and power only decreases emissions of greenhouse gases by 3.5%, as demonstrated above the benefit of replacing fossil fuel with energy from waste from an incinerator leads to a much more significant saving. As mentioned, only CHP incinerators are eligible for renewable obligation certificates, further to this they will soon be able to receive tariffs from the Renewable Heat Incentive, which is due to be implemented in April 2011. These economic drivers may appear to make CHP seem financially favourable to power-only incinerators. However, the capital expenditure of a CHP plant is the second highest of all renewable thermal energy technology available. The requirement to develop a district heating network to use the heat has been estimated at £1M per km of pipework. It is also considered a high risk investment as heat demand per m^3 in the UK is generally inconsistent with many areas having mixed building densities and sizes coupled with extreme temporal variation in heating requirements. Further as mentioned only the biogenic fraction of the waste is eligible for the incentive schemes. These are currently considered 50%, in 2013 this will drop to 40% and in 2018 to 35%. This will lead to a corresponding decrease in ROCs and any other financial incentives that may be eligible such as RHI. A study conducted on behalf of Veolia determined that upgrading to CHP from power only incineration was not economically viable without further government incentive (Faria, 2010).

4.5. Conclusions

GHG emission impacts have been shown to vary significantly with different electricity mixes. Processes that recovered energy from waste had significantly greater environmental burdens in all cases compared to the UK mix, with the Norwegian mix having the greatest difference, followed by the French and Lithuanian. In the comparison between the two different types of incinerator, the GHG impacts only varied by 3.5%. Resources depletion showed a similar pattern of variation between the different electricity mixes, for all scenarios, as the GHG emissions, as fossil fuel resources are included in the impacts inventory for this category. For all case studies the most significant increase in environmental burden was for the incineration scenario, followed by landfill, and MBT processes which produced significant amounts of stabilite. In contrast, processes that are net users of energy showed an

increased environmental benefit with Norwegian, French and Lithuanian mixes, compared to the UK scenario, as expected.

The two toxicity categories showed only small variations for all scenarios in all the comparisons presented, indicating that power generation does not emit significant concentrations of the pollutants that contribute to these categories. This is expected as emissions controls, regulated through the large combustion plant directive (Parliament & Council of the European Union, 2001a), and waste incineration directive (Parliament & Council of the European Union, 2000b) are very stringent and take human health into consideration.

Acidification potential showed insignificant variation in the first two cases, but processes that produced high levels of energy from waste showed a significant decrease in environmental burdens in the Lithuanian case compared to the UK. The open turbine gas technology employed in the Lithuanian marginal fuel mix is likely to be the cause of this, as the UK uses combined cycle gas turbine technology which prevents the release of acidifying pollutants.

The most significant pollutant variation seems to be related to NO_X emissions which contribute to both acidification and eutrophication. NO_2, which forms part of NO_X, is also identified as a risk to human health under local air quality regulations. However, power plants and waste treatment facilities would be sited so that concentrations would be diluted to safe levels by the time the gas reaches relevant receptors. The dilution actually occurs very rapidly. Vertical dilution has been determined through simultaneous measurements at ground and roof level close to a busy road and the difference in concentration has been found to be a factor of 5 (Vakeva et al., 1999, Qin and Kot, 1993, Zoumakis, 1995). In general concentrations measured at roof level showed little variation, in spite of strong variation in emissions at street level. Horizontally the dilution is a little more complicated, as it is dependent on the speed and direction of the wind (Johnson et al., 1973). However, dispersion still occurs within a short distance of the roadside, meaning receptors are only at risk in close proximity to the emission source.

Thus it has been shown environmental benefits of energy from waste have a significant dependence on the electricity mix that they are replacing. Energy from waste facilities often

have lifetimes of several decades and the UK is committed to increasing renewable and nuclear energy sources, in order to reduce GHG emissions, over a similar timescale. Therefore the results of the original WRATE modelling may not be valid, within the lifetime of the facilities they are assessing. The inability to alter background systems with time is one of the limitations identified in various studies (Ekvall et al., 2007, Winkler and Bilitewski, 2007). In Chapter 9 another limitation, relating to behavioural changes overtime, which could cause significant changes in residual waste composition is investigated, addressing the seventh objective of this thesis.

Much of the WRATE inventory relating to compost like outputs (CLOs) from MBT processes were based on quoted values from producers and data obtained in other countries, as plants had not been operational in the UK at the time WRATE was developed. The third objective of this thesis was therefore to investigate samples of these from UK based facilities and consider their environmental impacts in different uses. The first stage of this, presented in Chapter 5, was a characterisation of CLO samples.

5. Characterization of CLOs from biologically pretreated BMW

5.1. Introduction

In order to establish the most suitable use or disposal of CLOs, analysis of samples is important. In particular the continued biodegradability is of interest as this will determine the extent to which landfilling the outputs will contribute to LATS. Various biodegradability tests have been developed, which can be biological or non-biological. The Environment Agency (England and Wales) (Environment Agency, 2005) released a guidance document on monitoring MBT outputs, which was updated in 2009 (Environment Agency, 2009). These focus on biological tests, as most non-biological tests are still at the investigation stage.

Biological tests are either aerobic or anaerobic. Aerobic tests either monitor O_2 consumption or CO_2 production. The guidance document recommends the dynamic respiration index test (DR4) (Environment Agency, 2005) which involves passing air through the waste in an open system and measuring the difference in O_2 or CO_2 between the incoming and outgoing air. The limitation of these tests is they tend to preferentially decompose the readily degradable component and thus may not indicate potential long-term biodegradability. Anaerobic tests measure the production of methane and carbon dioxide from material maintained in anaerobic conditions until no further biogas is released, which can take up to 100 days. These tests are more representative of the conditions in a landfill, and therefore the results are more reliable but the long testing period makes them impractical for routine monitoring of an MBT plant.

Some non-biological tests are under investigation, and may prove more practical than the biological tests. An example is enzymatic hydrolysis (Wagland et al., 2008). This mimics the natural microbial hydrolysis of organic matter, including the inhibition of the cellulose substrate due to the presence of lignin. There are several limitations however. Firstly the waste must be sterilised in order to avoid microbial growth during the test. Autoclaving, which is the chosen sterilisation method, was found to greatly increase the degradable organic carbon measured. Also some of the non-biodegradable carbon present in the waste stream is likely to be measured and a way of avoiding this needs to be investigated further, so as not to overestimate the biodegradability. Commercially bought enzymes may contain varying levels

of activity, which can also affect the experimental results. Thus further investigation is required before this technique can be practically applied.

In this chapter, which addresses the third objective, analysis of samples obtained from four sites each operating a different biological treatment method are characterised for contamination of non-biodegradable components, moisture content, and cellulose, hemicellulose and lignin. During composting simple components will degrade first followed by hemicellulose, cellulose and lignin. Lignin is by far the most difficult to degrade, and can often appear recalcitrant if optimal conditions are not achieved (Richard, 1996). During anaerobic decomposition lignin remains recalcitrant and its presence can inhibit the degradation of cellulose, by physically limiting enzyme access to the cellulose substrate. Moisture content also influences the extent of stabilization and heat generation during aerobic treatment (Reinhart et al., 1993).

The characterisation method has been adapted from that used for measuring fibres in arable crops by (Harper and Lynch, 1981). The method is inexpensive, easy to carry out and takes four days. The results of the analysis are discussed in order to identify the factors that influence the composition of the outputs.

5.2. Materials and methodology

5.2.1. Sampling method

As mentioned, samples were obtained from four different biological treatment facilities. For the first two facilities, a simple random sampling method was used. Samples of approximately 400g were taken by hand and placed into re-sealable 25cm by 15cm bags, then placed in a second re-sealable bag to minimise degradation during transport. On receipt at the laboratory, samples were stored at 4°C to avoid any further degradation until analysis was performed. During collection, sample areas were thoroughly mixed by hand to make sure individual strata were not being sampled. Five samples were taken from each site.

Samples from facilities 3 and 4 were provided by the Open University and had been collected in accordance with the British Standards Institute guidance (BS EN 14899, 2005) on characterization of waste and then 2 kg sub-samples were provided to the laboratory.

5.2.2. Description of Samples

All four facilities used a different biological treatment process as described below:

Facility 1 (F1) is a compositing site accepting source-segregated garden and food waste only. Upon arrival the waste is visually inspected for non-biodegradable contamination and any unsuitable waste is rejected. It is then shredded down to 40cm and placed in a tunnel for 2 days reaching a maximum temperature of 60°C, before being moved into a second tunnel for 2-3 weeks reaching a maximum temperature of 80°C. The tunnel system has forced aeration and Gore-Tex^{TM} covers. Finally it is placed in a maturation shed for 5 weeks. For every 30 tonnes of green waste, approximately 5 tonnes of food waste is mixed in. Annually between 30,000 and 45,000 tonnes are treated. The operators aim to produce a compost of high enough quality for application to land as a soil conditioner the final product has particle size of 20mm.

Facility 2 (F2) is an anaerobic digester (AD) accepting source-segregated food waste from households, collected in corn starch bags and grass cuttings. The waste was a mix of approximately 98% food waste to 2% grass cuttings. Upon arrival the waste is shredded to homogenise the particle size and mixed with either digestate from the final storage tank, or recirculated digester contents. This is then pumped into the raw waste buffer tank, which is sized to hold approximately 4-5 days feed. This conditioned biowaste is fed into the digester every hour and digestate removed every hour. A continuous stirred tank reactor system is used to ensure contact between the biowaste and the bacteria in the digester. An optimum temperature of approximately 40°C is maintained. The retention time in the anaerobic digester is approximately 30 days. However, with the option to recirculate digester contents to mix with the feedstock this is more complex to define. Digester contents are then pumped into a pasteurisation unit where they are treated for 1 hour at 70°C according to ABPR (Statutory Instrument No. 2347, 2005). Pasteurisation occurs on a batch basis, approximately once or twice a week. This pasteurised material is then pumped into the storage tank where it remains until it is separated into fibre and liquor, recirculated or applied to land. The tank is sized to hold 3 months worth of digestate but retention times are hard to define. When the fibre and liquor are separated the fibre may remain in the digestate hall for up to two months (as did the sample obtained for this investigation).

Facility 3 (F3) is a composting facility accepting two week old MSW that has been coarsely screened. Upon receipt it is further screened down to a particle size of less than 40 mm. It is then composted for 6 weeks in a GORE^{TM} fabric system and further screened down

to particle size of 15mm. The aim of the site is to produce a "clean" compost like product (<6mm) that can be applied to land.

Facility 4 (F4) is an MBT plant accepting mixed black bag MSW. The waste goes through a bag splitter and is then trommel screened. The fines (<40mm) are shredded then composted in a Wright tunnel for 2 weeks. Wright composting is a continuously loading, fully enclosed, flow through in-vessel composting technology. The material that is produced is usually landfilled.

5.3. Analytical procedure

The first stage of characterisation was to examine visually the extent of physical contamination of non-biodegradable wastes. The moisture content was then determined through drying. The biological components cellulose, hemicelluloses and lignin were then characterised using a sequential digestion analysis. A method originally designed to analyse the chemical components of arable crops was modified for the purpose (Harper and Lynch, 1981).

Visual Inspection. The composite samples were thoroughly mixed by hand then a 400 cm^3 dish was filled to a depth of 2.5cm. A digital image was obtained of the spread. This was repeated three times with mixing occurring between imaging for each sample. The digital images were then analysed using the Image J (version 1.41) software, to determine the percentage area containing non-biodegradable waste.

Apparatus for Moisture and Biological Content Determination. Analytical balance accurate to 0.001g; Dessicator; Furnace (temperature 400°C±4); Drying oven (temperature 105°C±5°C and 75°C±0.7); 150 ml beakers; Hammer mill; Sintered glass Pyrex filter (porosity 250 μm); Metal crucibles; Flasks with sealable caps; Reagents; Distilled water; Acetone 99.5% v/v RECTAPUR; Ethanol 96% v/v GPR; 4.3M potassium hydroxide; 0.1M acetic acid; 0.2M sodium chlorite.

Pre-treatment of Samples. Five 400 g incremental samples for each output were placed into a large bucket and mixed thoroughly by hand for several minutes, to produce a composite. Samples were then milled using a hammer mill, with 2mm mesh.

Determination of Moisture Content. The weights of 5 x 150ml beakers were recorded. From the composite sample 5 x 2g samples were removed (mixing the material in the bucket after each sample), placed in the 150ml beakers and labelled accordingly. The samples were then placed in an oven and dried at 100°C for 16 hours. On removal from the oven the weights were recorded to indicate moisture loss.

Determination of Biological Content. The dried samples were then placed in a 50 ml solution of 0.lM acetic acid and 0.2M sodium chlorite in sealed flasks and incubated at 75°C for 3 hours. After the incubation the samples were filtered through porosity 160-250 μm glass sintered filter, washed with distilled water (five times), acetone (twice) and ethanol (once) and dried at 100°C for 16 hours. The weights were then recorded indicating lignin loss.

The samples were then placed in a 50ml solution of 4.3M potassium hydroxide in sealed flasks and incubated for 2 hours at room temperature. After the incubation the samples were filtered, washed and dried as before. The weights were then recorded indicating hemi-cellulose loss.

The samples were then placed in metal crucibles in a furnace at 400°C for 16 hours. The weight of the ash was then recorded indicating cellulose loss.

5.4. Results

5.4.1. Visual inspection

The received CLOs were all black or brown in colour and had a woody smell. The CLOs from F1 and F2 had the strongest odour, with F1 having an almost silage-like smell. The samples were inspected to identify any obvious non-biodegradable material. Samples from F1, which only accepts source-segregated kitchen and garden waste had very little physical contamination present. Samples from F2, which only accepts source-segregated food waste contained high levels of plastic bags. The food waste is collected in plastic bags made from compostable corn starch which appear to have only partially degraded in the anaerobic digestion process. Samples from F3 and F4, which both accept mixed MSW, had images of 2112 by 2172 pixels taken and analysed using Image J (version 1.41). It was found that the mean percentage area of non-biodegradable contamination of three random mixes of CLO from F3 was 8.9% with a standard deviation of 1.9. The results for F4 were 18.1% with standard deviation of 5.7, which suggests that F3 was of higher quality than F4 in terms of

non-biodegradable contamination. This was expected as the waste at F3 was subject to a more rigorous screening process. The contamination in F3 was made up mainly of plastic, glass and stone while in F4 there was glass, plastics, non-combustibles and metals. It should be noted that some of the contaminants especially stone, were difficult to isolate in the imaging analysis, while the glass and plastic were easily picked up. However, the methodology was still considered valid as it provided an indication of how the compost would be perceived by a customer, thus affecting its likelihood of being diverted from landfill.

5.4.2. Moisture, cellulose, hemicellulose and lignin content

The mean moisture, cellulose, hemicellulose and lignin contents measured for each facility were calculated from the results of the analysis of the sub-samples and are presented in Table 12 and Table 13 along with the standard deviation. The significance between the means of F1 and F2 is obvious due to the restriction in composition of the incoming waste stream. F3 and F4 are more likely to have had similar incoming waste composition; therefore an analysis of the statistical significance of the difference between the means of these two samples was performed. A two tailed T-test was selected as the most appropriate test.

Table 11: Cellulose, hemicellulose and lignin concentration of individual waste components in percentage of dry weight (Palmisano and Barlaz, 1996)

Component	Cellulose %	Hemicellulose %	Lignin %	Lignocellulose %
Grass	26.5	10.2	28.4	65.1
Leaves	15.3	10.5	43.8	69.6
Branches	35.4	18.4	32.6	86.4
Food Waste *	50.8	6.7	9.9	67.4
Office Paper	87.4	8.4	2.3	98.1
Coated Paper	42.3	8.4	15.0	65.7
Newsprint	48.5	9.0	23.9	81.4
Corrugated Boxes	57.3	9.9	20.8	88
Mixed Refuse a	51.2	11.9	15.2	78.3
Mixed Refuse b	28.2	9.0	23.1	60.3
Mixed Refuse c	48.2	10.6	14.5	73.3

Notes: * Data are the average of two samples, each of which was a composite of food waste collected in five kitchens over a 7 day period.

a Taken from Madison, WI 1987.
b Taken from Raleigh, NC 1992
c Taken from Raleigh, NC 1994

Table 12: Measured mean and standard deviation of biological characteristics for all four facilities

Facility	Moisture content (%)		Mean hemicellulose content		Mean cellulose content		Mean lignin content	
	Mean	SD	% wet weight	SD	% wet weight	SD	% wet weight	SD
1	33.4	0.5	10.9	0.5	10.2	1.6	22.3	1.3
2	73.7	2.1	2.3	1.7	7.1	0.7	7.4	0.5
3	26.3	2.9	5.5	2.2	8.5	3.6	17.4	1.9
4	58.7	2.0	5.4	0.4	12.1	2.6	14.1	0.6

Notes: SD = Standard Deviation

Table 13: Mean biological content by % dry weight

Facility	Mean hemicellulose content		Mean cellulose content		Mean lignin content	
	% dry weight	SD	% dry weight	SD	% dry weight	SD
1	13.1	1.1	15.2	3.1	26.9	2.1
2	8.5	4.6	24.3	9.1	28.2	2.1
3	7.5	2.1	11.6	5.0	23.8	3.3
4	13.0	1.0	29.2	4.9	34.1	1.6

Notes: SD = Standard Deviation

In order to assess the significance of the difference in the means between each group, an analysis of variance (ANOVA) test was performed on the results. The difference between the means of the moisture and lignin content were highly significant, while the difference between the means of the cellulose and hemicellulose content were significant.

As the incoming waste streams for F1 and F2 were so specific, a further analysis was performed on F3 and F4 to determine the significance between the two processes, as their incoming waste streams would have been the most similar in composition.

A student T-test was performed on these two sets of data. The results for moisture and lignin content were found to be highly significant and significant respectively, while the cellulose and hemicellulose content were both found to be insignificant.

5.5. Discussion

The first stage of the characterisation was a visual inspection to see the extent of contamination from non-biodegradable wastes. The visual inspection suggested that F1

produced the highest quality product with no visible contamination of non-biodegradable wastes present. The only contamination seen in the samples from F2 were the corn-starch based biodegradable bags the food waste was collected in. Although the conditions within the AD chamber may not have been conducive to degradation of this bio-plastic, for example light and oxygen can be essential to the breakdown process; these have been shown to degrade rapidly when applied to soils (Innocenti, 2005). Therefore the use of the outputs as soil conditioner should not be inhibited, although it might deter customers if the product appears to be full of plastic bags. F3 had a relatively small amount of glass and stone contamination, however, this is probably enough to limit its use as a soil conditioner. F4 had high levels of non-biodegradable contamination making it unsuitable for further use, so landfilling appears the only disposal option.

The application to land of CLOs from mixed MSW is a contentious issue. In England and Wales for example, the Environment Agency released a position statement (Environment Agency, 2008a) banning this practice on land growing food or fodder crops. The reasoning behind this precautionary approach is based on negative past experiences with application of mixed waste composts to land. It could potentially be used as restoration material, providing nutrients to land that has previously been built on and may be contaminated, however, the Agency is only willing to permit this in exceptional cases, rather than across the board due to previous problems such as the SU:BRIM project, which found that the application of organics to contaminated land mobilised the toxic metals as soluble complexes (Bardos and Chapman, 2008). Where land is accessible to the public, the presence of sharps in CLOs from mixed waste, such as broken glass presents a risk to health and safety. The Environment Agency's position is that risks need to be identified and hazards prevented, rather than leaving a clean-up legacy at sites where CLOs are to be used. The use of these outputs on industrial non-food crops may be a better option provided these are not publically accessible, but again it is important that true benefit is being provided to the soils and it is not just providing a convenient dumping place for wastes. These issues are considered in more detail in Chapters 7 and 8.

Thus source-segregation of biodegradable wastes has been shown to produce a better quality product, while screening of particle size has been only partially effective. The success of a segregated collection although theoretically a good option for reducing impacts of waste

management, could be limited by attitudes of the general public and the cost of arranging an extra collection. If participation rates are low, or the wrong things are placed in the separate bin, contaminating the waste stream, the diversion from landfill would be limited and the expense of arranging extra collection vehicles wasted. A recent study in the UK on the feasibility of a source-segregated food waste collection (Bridgwater and Parfitt, 2008) found the success could be achieved in some areas, but this was dependent on various social and economic factors.

The next stage of the characterisation was to determine the moisture content. In application to land, moisture content can be a bonus, especially in places of drought, although excess moisture can cause odour problems and increase transport costs. Drier composts can be dusty and may require addition of moisture for applications. In landfilling, moisture can enhance methanogenesis as it limits transport of oxygen, an inhibitor to methanogenesis, from the atmosphere, facilitates transport of microbes and nutrients between microenvironments and dilutes the concentration of other inhibitors (Christensen, 1996). However, excess moisture is considered to have an inhibiting effect on methanogenesis, generally greater than 70%. The anaerobic digestion process used in F2 operated as a liquid, and as expected its output had the highest moisture content. The composting process on the other hand allows for significant evaporation of moisture. In keeping with this, the moisture contents of the three composting processes showed a correlation with treatment time, see Table 12, F4 having the highest moisture content with only 2 week composting, F1 having next highest with 3-4 weeks composting and F3 having the lowest with 6 weeks composting. Dimambro et al. (2007) characterised 12 samples of CLOs from UK commercial composting plants Table 14. Their moisture contents ranged from 20.2 to 62%. The four samples analysed in this work have moisture contents within this range. The mixed MSW samples they analysed had moisture contents of 31.5 and 47.8%, our results fall outside of this range with F3 being lower and F4 higher. Six of the Dimambro CLOs contained significant incoming green waste streams, whose moisture contents ranged from 29.8-53.4%. The moisture content of sample F1 falls comfortably within this range.

Table 14: Moisture, cellulose and lignin contents (Dimambro et al., 2007)

Waste types	Process	Moisture content %	Cellulose %	Lignin %
green waste, kitchen, paper, cardboard	In-vessel	45	11.7	25.1
50% green waste, 50% fruit & vegetable	In-vessel	62	17.4	30.9
90% green waste, 10% milk	Windrow	39.5	11.4	23
Green waste, vegetable waste	In-vessel	46.7	9.4	20.6
75-80% straw, 20-25% green waste, fruit & vegetable, cardboard	Windrow	36.4	4.3	12.7
30-40% green waste, 60-70% fruit & vegetable, cardboard	Windrow	20.2	3	11.7
Mixed MSW	In-vessel	31.5	40.6	19.2
82% green waste, 15% potato waste, 3% manure	Windrow	45.9	10.8	23.1
Green waste, cardboard	In-vessel	29.8	7.8	16.8
Green & kitchen waste, paper, cardboard, catering waste	In-vessel	53.4	13.9	31
40% pet food, 40% shredded wood, 19% green, 1% lime	In-vessel	31.7	31.1	23.5
72% MSW, 17% kitchen waste, 11% commercial waste	In-vessel	47.8	34.4	19.4

The final stage of the characterisation was determining the content of the lignocellulose, by way of its three polymer constituents, cellulose, hemicellulose and lignin. The percentage of each component by dry weight is presented in Table 13. The highest lignin content was seen in outputs from F4, while F3, which also took in mixed MSW, had the lowest. Dimambro et al. (2007) also measured lignin content of two composted mixed MSW samples and found they contained 19.2 & 19.4 % by dry weight. The result for F3 is much closer to these values than F4 and is likely to be due to the difference in treatment time. Lignin is the most difficult component to degrade and it is unlikely that the brief composting period operated at F4 would have allowed any lignin degradation at all, while the 6 weeks at F3 would have allowed conditions for growth of lignin-degrading organisms to be established. Lignin is recalcitrant in anaerobic conditions and indeed F2 has the 2nd highest concentration at 28.2% dry weight. Comparing this value to the typical composition of incoming waste in Table 11, it is much higher than the given composition of food waste, 9.9% dry weight; however the lignin content of grass is given as 28.4% dry weight and may have had undue influence on our results as no degradation of lignin is likely to have occurred. Also the composition of food waste is highly variable and the measurement in Table 11 may not reflect the same kinds of food collected by F2. F1 had the 2nd lowest lignin content at 26.9% dry weight. Given the majority of the incoming waste was garden waste this was likely to have had a high lignin concentration to begin with, according to Table 11, up to about 44%

dry weight, therefore it is likely some degradation of lignin had occurred. Dimambro et al. (2007) measured lignin contents of 6 composts with a high proportion of incoming green waste and their lignin contents ranged from 16.8-31%, the value from this work falls within this range.

Cellulose is the next most difficult component to degrade. As with the lignin results, F4 had the highest cellulose content at 29.2% while F3 had the lowest at 11.6%. Dimambro et al. (2007) found 40.6% and 34.4% cellulose in their two mixed MSW samples which are much higher than our measurements. It is likely that variations in the incoming waste stream were the cause of this. The difference in measurement procedure may also have contributed to the discrepancy. Dimambro used the phenolic H_2SO_4 assay method (Dubois et al., 1956). Samples from F2 were found to have the 2nd highest cellulose content. The incoming cellulose content of food waste is also very high according to Table 11. Under anaerobic conditions the presence of lignin can limit enzyme access to cellulose substrates thus the extent of cellulose degradation is not expected to be very high. F1 had comparatively low cellulose content. According to Table 11, untreated garden waste would be expected to have a cellulose content of up to 35%. The cellulose results from Dimambro for the 6 garden waste heavy composts ranged from 7.8-13.9%. The measurement in this study of 15.2% lies just outside this range, but within one standard deviation.

Hemicellulose is the easiest to degrade of the three lignocellulosic components. It is also the least abundant of the three according to Table 11 where the range of hemicellulose contents ranges from 6.7% to 18.4%. F1 was found to have the highest hemicellulose content, but garden waste is higher in hemicellulose than other components of untreated waste, therefore it is likely this is due to the restricted incoming waste stream rather than the treatment process. F4 also had high hemicellulose content, again the short treatment time would have not allowed for significant degradation. The untreated hemicellulose content of food waste, according to Table 11 is low compared to the measured hemicellulose content of F2; however, the food waste sampled in Table 11 was taken from a different time and a different place and is therefore only a rough comparison to the wastes being examined in this investigation. F3 again had the lowest hemicellulose content as its long treatment time would have allowed for more significant degradation.

5.6. Conclusions

In relation to the overall aim of this thesis, it is important to note that the further use of these CLOs will lead to further degradation, whether they are to be applied to land or landfilled. The results from F1 and F2 indicate that the composition of the incoming waste stream is the main factor influencing the biological content of the outputs. F3 and F4 show that the length of treatment is the next main factor.

In the following chapter the results of this characterisation will be used to predict the rate of degradation in a landfill environment and the resulting gas emissions. It is important to understand how they might degrade once placed in this anaerobic environment for effective sustainable landfill management.

6. Modelling gas emissions from landfills accepting CLOs

6.1. Introduction

The definition of landfilling varies greatly throughout the world, and can refer to what are essentially open dumps, where waste is placed in a hole in the ground with no further treatment to highly engineered sanitary landfills, which have liners and systems to enable the capture of most of the liquid and gaseous emissions. While the benefit of partially reducing the biodegradability of MSW in an open dump is obvious, where sanitary landfilling is practised, concerns have been expressed over how it will affect the ability to capture the gas. There is some concern that the time taken for a site to achieve a state where the emissions are naturally attenuated by the surrounding environment and no longer require external management will remain the same as landfills accepting untreated waste (Knox and Robinson, 2007). The loss of revenue from recovering energy from landfill gas is also of great concern for landfill operators, particularly where these are operated as private businesses.

The biodegradable fraction of MSW is composed predominately of cellulose, lignin and hemicellulose. Cellulose and hemicellulose degradation can occur in both aerobic and anaerobic conditions, while lignin only degrades aerobically. The presence of lignin in anaerobic conditions also reduces the degradation rate of cellulose, believed to be due to physically limiting the surface area of cellulose available for microbiological activity (Richard, 1996). The biodegradation processes that occur in landfills have been described in various publications (Christensen, 1996), (Palmisano and Barlaz, 1996) and (Williams, 2005). Figure 16 illustrates the processes, briefly any oxygen present is depleted producing carbon dioxide and water. Hydrolysis processes then reduce carbohydrates to sugars allowing growth of acidogens. These reduce sugars to organic acids allowing optimum conditions for acetogens which metabolise organic acids into acetic acid. This provides a substrate for the growth of methanogens which produce methane and carbon dioxide. This last phase, known as methanogenesis, is the longest stage but may not commence until 6 months to several years after initial deposition depending on landfill characteristics. High methane generation occurs for between 3 and 12 months, depending on the development of the anaerobic micro-organisms and waste degradation products. Significant amounts of landfill gas will continue

to be generated for between 15 and 30 years after final deposition of the waste, depending on waste and site characteristics. However, low levels of landfill gas may be generated for up to 100 years after waste emplacement (Williams, 2005). Methane and carbon dioxide generally make up over 90% of landfill gas, the balance between them depending on the degradation phase. Other gases present include oxygen, nitrogen, hydrogen, and many trace gases.

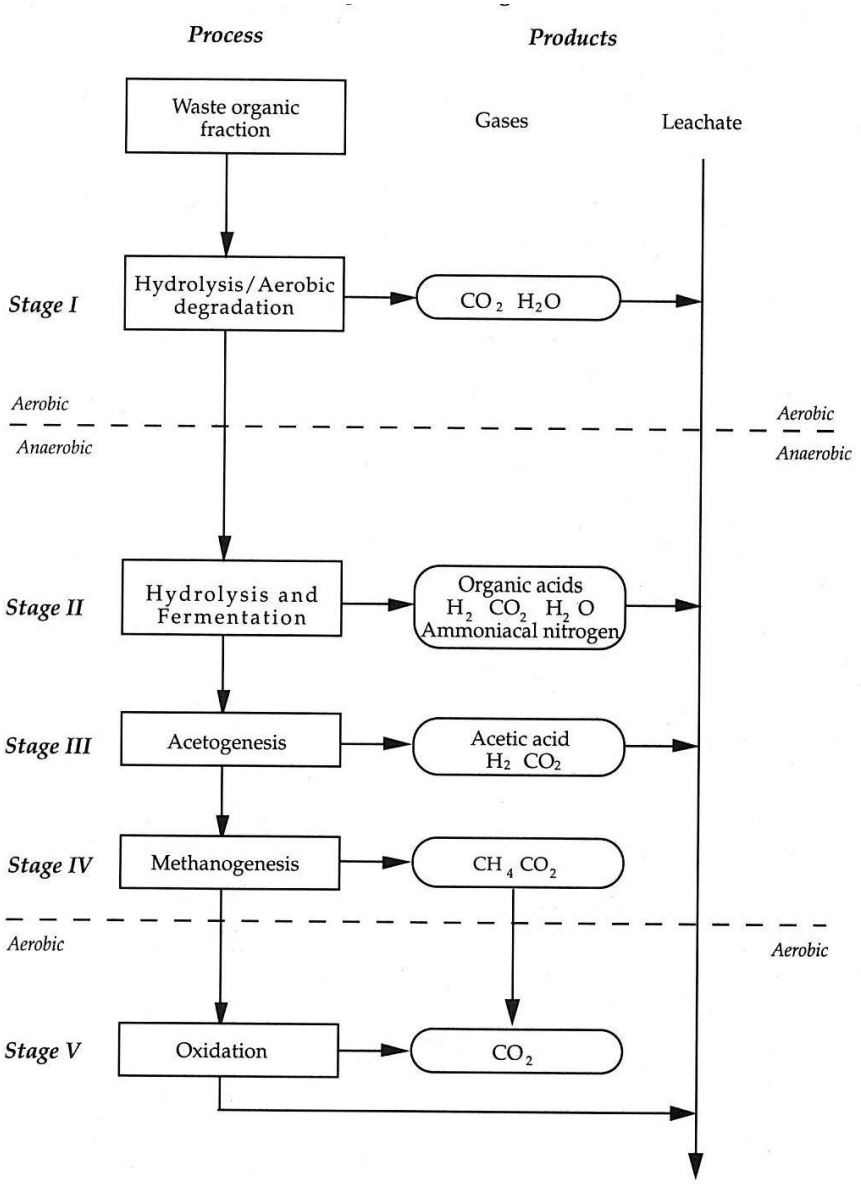


Figure 16: Stages of waste degradation in anaerobic landfill (Department of the Environment, 1995)

The growth of the microorganisms, especially methanogens are sensitive to a variety of environmental and operational conditions including moisture content, pH, temperature, sulphates, nutrient availability and oxygen and hydrogen presence (Christensen, 1996). The moisture content has been shown to significantly enhance the production of methane as it

limits transport of oxygen from the atmosphere (an inhibitor of methanogenesis); facilitates transport of microbes and nutrients between microenvironments; and dilutes the concentration of inhibitors.

In this chapter gas generation in a landfill accepting large quantities of CLOs is modelled. Many approaches to modelling emissions from landfill have been investigated and a brief review of these is presented in section 5.2, along with a description of the GasSim model (v1.03) (Environment Agency, 2004). The discussion focuses on the impact the CLOs may have on the future of sanitary landfill management in terms of mitigating gaseous emissions and thus the potential environmental burden in terms of GHG emissions of this disposal option. The results are compared with the LCA results in Chapter 3 for MBT processes producing stabilite.

6.2. Modelling landfill gas emissions with GasSim

The GasSim model is based on a first order kinetics approach to Monod kinetics.

Monod kinetics describes microbial growth rate as shown in equations (1) and (2):

$$dX/dt = (\mu_m SX/(K_s+S)) - K_dX \quad (1)$$

$$dX/dt = Y\, dS/dt \quad (2)$$

X = microbial population concentration, mg/l

μ_m = maximum specific growth rate, d^{-1}

S = limiting substrate concentration, mg/l

K_s = half saturation constant, mg/l

K_d = decay rate, d^{-1}

Y = cell yield coefficient, mg of cells synthesized/mg substrate utilized

t = time, d

Two mathematical simplifications of the Monod kinetics equation are commonly used. The first, equation (3), is where the limiting substrate constant, S is much greater than the half saturation constant K_s:

$$S >> K_s;\ dS/dt = ((\mu_m - K_d)X)/Y \qquad (3)$$

This is known as a zero order kinetics equation. This means that the main factor influencing the decomposition rate is not the substrate availability, but another parameter for example moisture content. The amount of gas produced would be limited to a constant value independent of time. Experimental data (Ham and Barlaz, 1989) appears to show good agreement with this type of modelling, particularly during the stage of most active gas generation. However, in modern sanitary landfills this situation would indicate unfavourable conditions.

The second, equation (4) is where the limiting substrate concentration is much smaller than the half saturation constant:

$$S << K_s;\ dS/dt = (1/Y)\ ((\mu_m S/K_s) - K_d)X \qquad (4)$$

It is known as a first order kinetics equation and in this case the amount of substrate available is the main limiting factor in landfill gas production rate. This is the most popular approach to modelling, even though moisture content can often have a stronger influence on gas generation rates. Sensitivity analyses such as those by El-Fadel et al. (1997b) and Meima (2008) have found the strongest influence on methane production is related to the hydrolysis process, which is strongly linked to moisture content. Temperature and nutrient availability have also been shown to have a significant influence.

A more complex approach to modelling gas generation is to describe the various stages of microbial degradation in sequence through a series of equations. These types of models can become complicated due to the number of different input materials, the large number of processes going on in the landfill and the number of different factors influencing each one. The GasSim model uses a simplified approach to classifying the degradability of different

components of the waste as slow, medium or fast, rather than considering each component separately, appears to correlate well with experimental data obtained from landfill sites.

(see equation (5))

$$C_t = C_0-(C_{0,1}e^{(-k_1 t)} + C_{0,2}e^{(-k_2 t)} + C_{0,3}e^{(-k_3 t)}) \text{ and } C_x = C_t - C_{t-1} \quad (5)$$

Ct mass of degradable carbon degraded up to time t (tonnes)

C_0 mass of degradable carbon at time t = 0 (tonnes)

$C_{0,i}$ mass of degradable carbon at time t = 0 in each fraction (tonnes)

C_x mass of carbon degraded in year t (tonnes)

t time between waste emplacement and LFG generation (years)

k_i degradation rate constant for each fraction of degradable carbon ($year^{-1}$)

It also allows detailed input of moisture content, which as explained above is important for methane generation. There are two ways in which this is done, depending on available data. The first allows input as 'dry', 'wet' or 'average' which is taken as less than 30%, between 30% and 60% and greater than 60% respectively. However, it is suggested in the user manual, if moisture content exceeds 70% the excess moisture can have an inhibiting effect on methane generation and it is recommended a 'dry' landfill be used. The second method calculates the moisture content based on infiltration, waste density, effective porosity, leachate head, hydraulic conductivity, adsorptive capacity and leachate recirculation.

All inputs can be entered as a probability distribution function, to reflect the unpredictable nature of landfills. The model then performs a Monte Carlo simulation. The number of iterations is user-defined, giving control over the statistical significance of the results.

As mentioned in the introduction Pan and Voulvoulis (2007) used GasSim to estimate the contribution to methane generation from each biodegradable waste component. Here the same methodology is used to investigate the gas potential of the CLOs characterised in Chapter 5, addressing the fourth objective of the thesis. A summary of the processes is presented in Table 15 for ease of reference. The overall reduction in methane emissions from landfills with biostabilised wastes has been investigated previously (Komilis et al., 1999, Mahar et al., 2007). The long term emissions may be of greater concern to the future of

sanitary landfilling, where emissions must be controlled until the sites are considered to be 'at equilibrium', thus the overall aim is being addressed, as the long term impacts of landfilling could make a significant contribution to the total environmental impacts of a waste management system.

6.3. GasSim modelling methodology

The main inputs to GasSim are annual rainfall, site geometry, composition of cap and liner, and quantity and composition of waste deposited per year. The predefined 'Berkshire Landfill' contained within the model was used for all parameters except waste composition. This site was chosen as being the most representative of a MSW landfill available. The site was operational for 23 years, between 1978 and 2001 and accepted a total of 1,617,860 tonnes of domestic waste in its lifetime. 100 iterations were chosen to provide good statistical results, without being impractically long to run. Gas generation was simulated for a period of 150 years from the year the site began accepting waste. The balance between methane and carbon dioxide is input by the user. In this case methane was defined as a normal distribution with mean 55%, standard deviation 5% and carbon dioxide with mean 45%, standard deviation 5%.

Table 15: Biological treatment processes

Site	Waste accepted	Treatment	Final destination
F1	Source segregated household kitchen (14%) and garden (86)% waste	Composting 60°C for 2 days, 80°C for 2-3 weeks. Tunnel system, forced aeration, GORE™. Matured for 5 weeks	Soil conditioner (20mm)
F2	Source segregated kitchen waste (98%) and grass cuttings (2%)	Anaerobic digestion continuous stirred tank reactor system at 40°C, followed by pasteurisation	Soil conditioner
F3	2 week old coarsely screened (<40mm) MSW	Composted for 6 weeks using GORE™ and further screening	Soil conditioner (< 15mm)
F4	Mixed black bag MSW	Bag splitter, trommel screened, shredded composted for 2 weeks (Wright compost technology)	Landfilling

The waste is defined by categories such as domestic, commercial, industrial etc. The composition of each of these categories is defined as percentages of different waste streams including paper/card, textiles, miscellaneous, putrescible, sewage sludge and non-degradable with some of these broken down into sub-categories, see Table 16. Each of these waste streams is defined by moisture content, cellulose, hemicellulose and degradability.

In this study the 'domestic' waste category was redefined based on the waste composition given in the Waste Strategy for England, 2007 (Defra, 2007b), (Table 16), to provide the base case for a typical present day landfill for comparison with the CLO scenarios. The samples characterised for their cellulose, hemicellulose and moisture content in Chapter 5 were used for the remaining scenarios. Table 17 summarises the results for ease of reference. These results were input as a normal distribution under the 'Composted' waste stream.

Nine scenarios were modelled: the base case waste stream only, CLOs only for each of the four types and half CLOs-half base case for all four CLO types. It was difficult to determine a realistic combination of raw and treated waste, as issues such as recycling rates, alternative uses for CLOs and future waste arisings were beyond the scope of this investigation.

Table 16: Waste Streams

Waste Fractions		**Base case (%)**	**CLOs only (%)**	**Half-half (%)**
Paper/Card	Newspapers	6.11	-	3.06
	Magazines	2.62	-	1.31
	Other paper	5.41	-	2.71
	Liquid cartons	0.27	-	0.14
	Card	2.06	-	1.03
	Other card	1.52	-	0.76
Textile	textile	3	-	1.5
Miscellaneous	Disposable nappies	2	-	1
	Other misc.	14	-	7
Putrescible	Garden waste	20	-	10
	Other	17	-	8.5
Fines	10mm fines	3	-	1.5
Sewage sludge	Sewage sludge	-	-	-
	Composted	-	100	50
	Incinerator ash	-	-	-
Non-degradable		23	-	11.5

6.4. Results

The generated data were analysed in three different ways. Firstly the total methane generation of the landfill over the 150 year simulation period was calculated. This is presented in Table 18 as a percentage reduction compared to the base case. As expected methane generation was reduced for all four CLOs in both scenarios. The greatest reduction in methane generation was from F2 which was an anaerobic digestion process accepting only kitchen waste and grass. It had low hemicellulose, high cellulose and lignin, and very high

moisture content. The high moisture and lignin content are both likely to inhibit methanogenesis. The least reduction in methane generation was from F1, which was a composting process accepting only source-segregated garden and kitchen waste, had average moisture and high hemicellulose content. Therefore these results correlated with the measured biological components and moisture contents.

Table 17: Mean measured percentage moisture, cellulose and hemicellulose content and standard deviation

Facility	Mean moisture content		Mean hemicellulose content		Mean cellulose content	
	%	Standard deviation	% dry weight	Standard deviation	% dry weight	Standard deviation
F1	33.4	0.5	13.1	1.1	15.2	3.1
F2	73.7	2.1	8.5	4.6	24.3	9.1
F3	26.3	2.9	7.5	2.1	11.6	5
F4	58.7	2	13	1	29.2	4.9

The next part of the analysis profiled the time over which the emissions were released. These are presented as average methane generation in cubic metres per hour for each simulation year. Figure 17 shows the results for base case waste stream, with the four landfills accepting half CLOs-half raw waste. Figure 18 shows the base case with the four CLO only scenarios. As can be seen methane production followed a similar pattern for all outputs in all scenarios of an initial steady increase in production up to a peak at 14-16 years, followed by a slow decline.

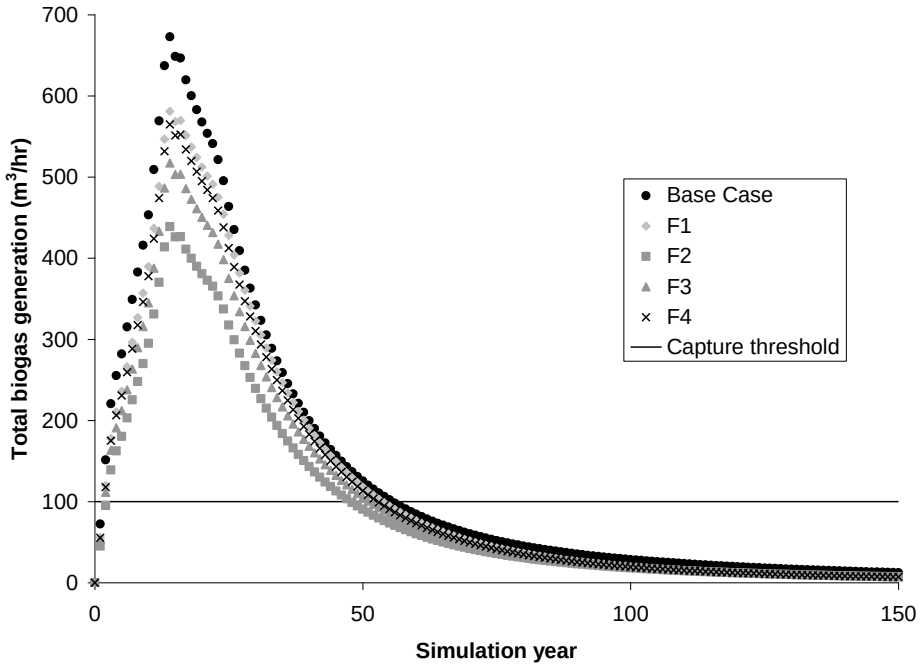


Figure 17: Gas emissions from landfills accepting half CLOs – half raw waste

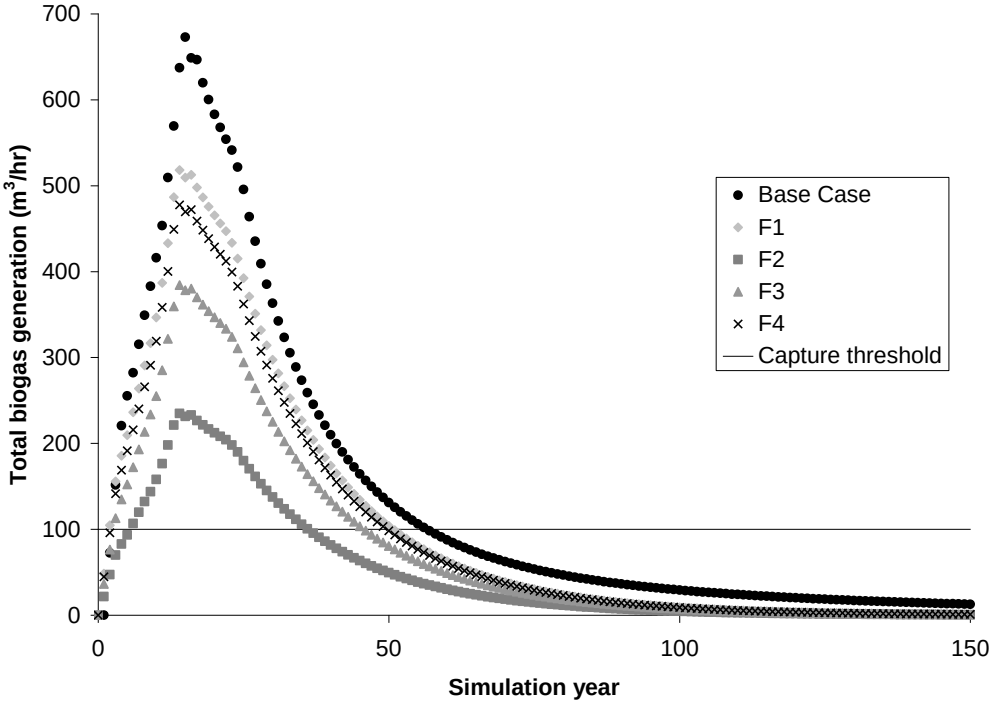


Figure 18: Gas emissions from landfills accepting CLOs only

The final part of the analysis considered the time for which gas capture from the landfill would be difficult due to the emission rate being too low. Table 18 also shows the percentage time over which the landfill will be producing gas at rates of less than $100m^3/hr$. This

production rate is considered the threshold of ability to effectively capture landfill gas for energy recovery. At rates lower than this some gas will inevitably be passively venting to atmosphere. The base case is predicted to emit below this threshold for approximately 65% of its lifetime. Figure 19 and Figure 20 illustrate the emissions lifetime at below this threshold rate for both scenarios.

Low flow rate combustion flares are available which can deal with emissions down to approximately $10m^3$/hr and new technologies to treat lower flow rates than this are emerging. The percentage of the 150 year lifetime the landfills will be emitting at below this threshold is also presented in Table 18.

Table 18: Methane reduction compared to the composition data given in the waste strategy for England 2007 and also lifetime of landfill gas passively venting

Scenario	CLO source	Lifetime methane reduction (%)	% of lifetime landfill gas generation <100m^3/hr	% of lifetime landfill gas generation <10m^3/hr
Base case			64.7	<1
Half-half	F1	11.7	66.0	14
	F2	32.9	70.7	14
	F3	21.7	67.3	13.3
	F4	13.3	66.7	14.7
CLOs only	F1	23.8	68.0	35.3
	F2	65.0	80.0	46.0
	F3	42.5	72.0	38.7
	F4	28.5	69.3	36.0

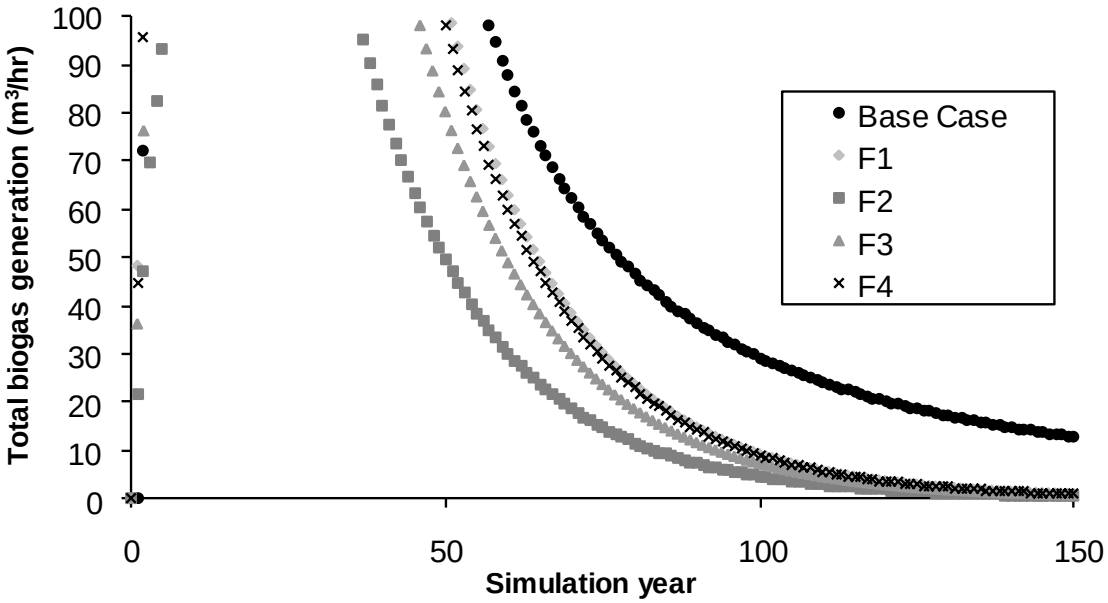


Figure 19: Gas emissions below 100 m^3/hr from landfill accepting half CLOs – half raw waste

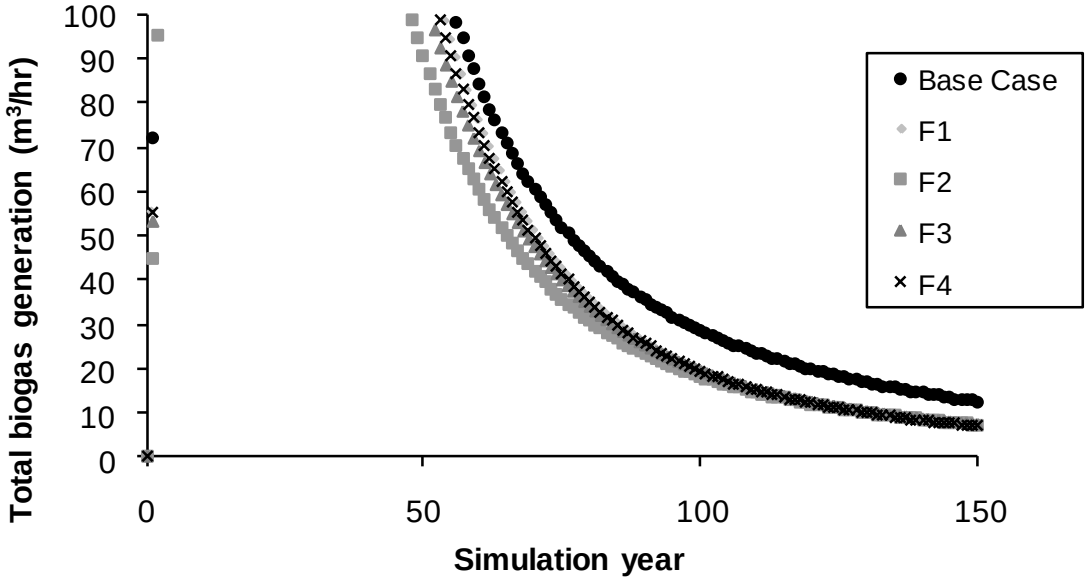


Figure 20: Gas emissions below 100 m^3/hr from landfill accepting CLOs

6.5. Discussion

The first stage of the analysis showed a significant reduction in overall methane generation of a landfill, in agreement with Komilis et al. (1999) and Mahar et al. (2007). As mentioned this reduction in emissions will have a positive impact on the environment if no attempt is

made to mitigate gas emissions. Where the mitigation of gaseous emissions is being practised, which is a legal requirement in the EU, the impact that landfilling of CLOs will have on emissions over time is of greater concern. Figure 17 and Figure 18 indicate that gas emissions will continue to occur over long time periods, similar to those for untreated waste, reflecting the results of Knox and Robinson (2007) that indicated even though significant reduction in the peak emissions, the long term emissions tail of landfills would be similar to that of untreated waste. The low flow rates will make it difficult and more expensive to capture the gas and limit the ability to utilise it.

The Environment Agency's 'Guidance on Landfill Gas Flaring' states that a practical threshold for combustion is $100m^3$/hr (Environment Agency, 2002). Many models also assume that combustion in flares will fail at this rate and in practice, it has been found that with poor gas collection infrastructure, combustion may actually fail at generation rates of $180m^3$/hr (Rosevear, 2008 personal communication). Table 18 indicates the percentage of the 150 year lifetime that the landfills are likely to emit below this threshold. In the base case scenario it is 64.7% of the time. In the half-half scenario it is increased slightly but stays within 6% of this value ranging from 66.0% for F1 to 70.7% for F2. In the CLO only scenario F2 is increased to 80%, however, it is unlikely that a CLO only landfill will be created. For example, paper and card that emit low amounts of methane over long periods of time are likely to be present, which will increase these emission rates in the later years of the landfill. However, it is expected that these scenarios will still result in a significant reduction in the amount of revenue generated through selling the gas as a renewable energy source.

It will also be necessary for landfill operators to invest in low volume landfill gas flares with re-igniters in order to achieve the necessary gas controls. These can deal with gas volumes down to approximately $10m^3$/hr (uniflare.co.uk) (development of flares that can deal with volumes lower than this are under way and so maybe available soon). To investigate the impacts of this, a threshold of $10m^3$/hr was assumed and is also presented in Table 18 as a percentage of landfill lifetime emission rates. The base case emits gas for less than 1% of the 150 years. The CLOs only scenario shows a significant increase in the time scales of this emissions rate of up to 46% for F2. This is of concern as it is likely this will be emitted untreated to the atmosphere. Although it is unlikely that a landfill would contain CLOs only,

even the time for the half-half scenario increases to 14%. This amounts to approximately 1055 tonnes of carbon dioxide equivalents per year.

In the CLO only scenario the gas emissions were reduced to less than $1m^3$/hr by 102^{nd} year. Therefore the other components of the waste stream are making a more significant contribution to the gas at this stage. This agrees with the findings of Pan and Voulvoulis (2007) who modelled individual fractions of the waste stream and found that long term emissions were probably attributable to the slowly degrading paper/card fraction.

Instead of simply landfilling CLOs it is possible to use them as a landfill cover. In this role they can act as medium for microbial methane oxidation. CLOs fulfil the criteria of a material suitable for this application including high porosity, high water retention capacity, suitable nutrient level and sufficient biochemical stability, so respiration of other microorganisms diverting oxygen away from methane oxidisers is prevented. Einola et al. (2008) found that cover layers of CLOs could provide reductions in greenhouse gas emissions from landfills all year round and even in cooler northern European climates. Leikam (1999) also found that if MSW is composted for 6 months or more it will be suitable for landfill cover. In order to achieve methane oxidation, the layer should be of low density and comprised of a large proportion of structural material. However, composting operations for municipal waste are often practised on much shorter time scales due to the constant high level of waste being generated and the land use requirements of composting processes. Before increasing the composting time it would be necessary to consider these practicalities.

Another method for mitigating greenhouse gas emissions from landfills post deposition is forced aeration techniques that flush the waste with oxygen, inhibiting the growth of methanogenic bacteria and thus reducing the formation of methane. Gas from aerated landfills would comprise carbon dioxide, water and trace pollutants. Results from a variety of experiments using aeration techniques have shown aftercare periods can be reduced by decades (Rich et al., 2008). Some concern has been expressed about possible emissions of the potent greenhouse gas, Nitrous Oxide (N_2O). Vor et al. (2003) found that N_2O emissions from aerated nitrogen rich soils were more likely to be significant where pockets of aerobic and anaerobic conditions exist, as would be the case in an aerated landfill. However, the generation of trace gases is difficult to measure because of the rate of transport of gases through waste (Powell et al., 2006). The energy requirements of aeration techniques have

been shown to be less than the emissions saved in some cases (Ritzkowski and Stegmann, 2007), however, this is dependent on energy generation method and the suitability must be considered on a case by case basis.

6.6. Comparing GasSim and LCA results

The results generated from GasSim can now be converted from m^3/hr to kg CO_2 equivalents in order to be able to compare them with those obtained in the LCA in Chapter 3. This analysis will be used for comparison with the scenarios which produced stabilite: Haase, Arrowbio, Global renewables, Linde and VKW.

The first stage of the conversion was to split the landfill gas data into 3 groups, less than 10 m^3/hr, which was assumed to be released to the atmosphere; greater than 100 m^3/hr which was assumed to be converted to electrical energy; and between 10 and 100 m^3/hr which was assumed to have been flared converting methane into CO_2 and water.

To convert emission rates of less than 10m^3/hr to kg CO_2 equivalent, the results were multiplied by 0.68 to convert from m^3 to kg (Air Liquide, 2009), and then multiplying by 23 to convert to kg CO_2 equivalent in accordance with IPCC guidelines.

In order to calculate the offset benefit of electricity generated from landfill gas, The Carbon Trust defines landfill gas as giving between 5.8 and 7 kWh per m^3, (The Carbon Trust, 2006) which is in good agreement with the landfill flaring guidance (Environment Agency, 2002) and the science data book (Tennant, 1986) that give the value as approximately 5. The calculations were performed using both these values and are presented as a range in Table 19. First the m^3/hr were converted to kWh/hour by multiplying by the factors defined above, then multiplied by the number of hours in a year (8765.67) to give total kWh. The values were summed to give the total kWh generated over 150 year period modelled. The offset benefit of this was calculated against the marginal electricity fuel mix for the UK 2010, as defined by the WRATE model. The CO_2 equivalent emissions of each fuel type were taken from The Carbon Trust leaflet. The offset benefit was then subtracted from emissions, to give the total CO_2. The results are shown in Table 19 along with the landfill CO_2 values for stabilite determined in WRATE.

Table 19: CO_2 equivalents from the landfills accepting CLOs analysed in Chapter 5

	100% scenario		50% scenario	
F1	-3.5E+06	4.2E+06	7.9E+06	1.7E+07
F2	3.1E+07	3.3E+07	3.2E+07	3.8E+07
F3	1.2E+07	1.7E+07	1.8E+07	2.6E+07
F4	-4.1E+05	6.5E+06	1.0E+07	1.8E+07
Haase	1.2E+07			
Arrowbio	1.7E+07			
Global renewables	1.3E+07			
Linde	5.7E+06			
VKW	1.6E+07			

As can be seen, the results from the GasSim modelling are in good agreement with those from WRATE, especially in comparison with the 50% scenario, which is more appropriate as the WRATE scenario assumed a proportion of each type of waste in the residual stream, and a certain amount of reject, rather than a landfill accepting only CLO. Haase, Arrowbio, Global Renewables and VKW all fall in the range of the 50% scenario of F4. This was the shorter composting time MBT process and therefore had the least degradation. Haase, Arrowbio and Global Renewables all had an anaerobic digestion process as their biological treatment. Global Renewables was coupled with biodrying, so would have a lower moisture content going into the landfill. The Linde result is below the bottom of the ranges for F3 and F4, and is closer to the bottom end of the range for F1, indicating this would have had a longer biological treatment.

7. Marketability of MBT outputs: SRF and CLOs

7.1. Introduction

As shown in the previous chapter sending CLOs to landfill does not significantly ease the environmental burden of landfill management. Further to this, most MBT operators would like to produce a marketable product that they can sell for a profit, rather than sending the outputs to landfill and incurring gate fees. Landfilling is more commonly seen as a final resort for non-compliant products, or market failures. Marketability is therefore an important consideration. SRF is a more attractive option than "compost" at the moment as it produces a saleable product, with a customer base in energy intensive industries. The UK government is committed to increasing energy from renewable sources and reducing GHG emissions, and energy intensive industries are statutorily obligated to participate in achieving these goals. The role of SRF in this regulatory framework will be described in the second part of this chapter.

Co-combustion of fossil fuels with biomass has been shown to have a reduced environmental impact compared to burning coal on its own (Benetto et al., 2004). The advantage of SRF production over landfilling or direct incineration has previously been shown by life cycle assessment (Cumbria County Council, 2008) provided the SRF is used efficiently. The advantage over incineration of untreated waste is due to its ability to directly offset the use of coal, although this depends on transport requirements, calorific value and the efficiency of combustion. Further the ash residues from combustion of SRF have been shown to have lower hazardous content than ash from combustion of untreated waste (Balampanis et al., 2010). This reduces the impacts of disposing the ash residues and increases the potential for them to be recycled into construction materials.

As the environmental benefits of SRF production are dependent on efficient use, end user perception of the product is very important. The third section of this chapter will summarise the results of a series of interviews conducted by Amar Lochab, during his MSc at Imperial College (Lochab, 2009), with the following SRF producers as well as current and potential users: Liam Welsby from Shanks; Brotherton from Scotgen; H. Bobat from Buxton lime and cement; John Watson from Scottish and Southern energy; Andy Carling from E.ON; Nick Barnett and David Crowther from Centrica; Lynn Clarke from Biffa; Kevin Whitmore Sinfin

Lane, Derby; David Longden from Energos; Kevin Riley from Biossence; Baker from New Earth Solutions; and Toney Sharkey from Yorwaste. These give an indication of current and planned SRF production, potential for expansion of SRF use and thus the potential contribution to diverting biodegradable waste from landfill. Previous work for Defra into the market for SRF involved *entirely desk-based research, no direct contact was made with the identified facilities (comments received from biomass facilities are taken from a previous RPS study). The potential for the facilities to use SRF has been estimated based on publicly available information and the experience of RPS staff. It is recognised that this data is often incomplete and/or only best estimation, and further refinements to the search criteria are recommended (Arias-Garcia and Gleeson, 2009a,b,c,d,e).* Therefore the interviews reported here built on the knowledge accumulated by Defra by obtaining real opinions from the four main energy using industries.

The final part of this chapter considers the marketability of composts from mixed waste, and the regulation surrounding the use of these.

7.2. Regulation of SRF use

As mentioned in the introduction, SRF must comply with the international standard. The classification system is based on three parameters: an economical parameter (net calorific value); a technical parameter (chlorine content); and an environmental parameter (mercury content). However, the minimum standards have been found to cause problems in furnaces during co-combustion. In particular the chlorine content is considered too high and the calorific value too low (ECOS, 2008). A trial at Slough Heat and Power replacing their normal fibre fuel with SRF from MSW found that the high chlorine levels increased corrosion rates meaning boiler parts that normally would have only required cleaning had to be replaced. They concluded SRF should be at most 10% of the fuel feedstock. The development of a new boiler more tolerant to high chlorine levels is being investigated and could make the product more marketable (Watson, 2008). In the mean time the success of SRF use will depend on savings compared to fossil fuel use and economic incentives offset against increased costs of cleaning, APC residue production and lime consumption.

Energy intensive industries with a thermal capacity of 50 MW or more will already be regulated through the large combustion plant directive (2001/80/EC) (Parliament & Council of the European Union, 2001a), which aims to limit emissions of SO_2, NO_X and particulate

matter, as these are known to cause damage to human health and contribute to acid deposition. In order to use SRF, they will also have to comply with the WID (Parliament & Council of the European Union, 2000b) which covers all energy from waste operations including dedicated incinerators; co-incineration plants, those utilising untreated waste, or SRF. The WID specifies emissions limits for the same pollutants, only they are much more stringent (values are presented in Appendix C). Another requirement is to obtain waste handling permits in compliance with the environmental permitting regulations (Statutory Instrument No. 3538, 2007).

Legislation that could encourage the use of SRF stems from the government's commitment to reducing GHG emissions and increasing energy from renewable sources. The Climate Change Levy, a tax applied per kilowatt hour of energy consumed by non-domestic users (Defra, 2001) can be reduced by up to 80%, if a strategy to improve energy efficiency and/or move towards renewable energy sources is devised. By switching electricity supply to an accredited renewable source, which the biogenic content of SRF qualifies for, companies will receive a Levy Exemption Certificate (LEC). The EU emissions trading scheme (ETS) (Parliament & Council of the European Union, 2003c) introduced in January 2005, is aimed at power generators, several specific energy intensive industries and any other sites combusting more than 20MW of thermal energy annually. Relevant sites have been granted emissions credits based on their CO_2 output. The number of credits relates to the permitted CO_2 emissions in a given year, with allowed credits decreasing over time. Plants that exceed the emissions allowance are required to purchase the appropriate number of credits, while those that emit less, can sell the excess credits. Emissions from the combustion of the biogenic fraction of SRF will not count towards GHG emissions, thereby reducing the number of carbon allowances a company is required to purchase or even leaving them with excess allowances to sell.

The UK is obliged to increase energy from renewable sources to 15% of power generation by 2020 under European legislation (Parliament & Council of the European Union, 2001b). To aid compliance with the directive the Governments of the UK introduced the renewable obligation order in England and Wales and the Renewable Obligation Order (Scotland) in Scotland in April 2002. The renewable obligation (Northern Ireland) came into effect in April 2005. Under the order companies are required to source a set percentage of energy from

renewable sources in each year. For 2006/07 the obligation was set at 6.7% in England, Wales and Scotland, and 2.6% in Northern Ireland. For each MWh of electricity produced from a renewable source, companies will receive a renewable obligation certificate (ROC). These certificates will show the companies' compliance with the order. Companies with an insufficient number of ROCs will have to pay into a fund that will be awarded to companies that do comply. The biogenic content of SRF makes it eligible for ROCs. Another incentive, specifically designated for cement and lime manufacturing installations, among other things, is the Substitute Fuels Protocol, which encourages the cement kiln industry to source part of their energy from SRF by relaxing emissions limits and lowering the calorific value limit (Garg et al., 2007).

A consultation in 2008 on renewables indicated that there was a high risk of failing to reach the 2020 target, and that further incentive would be necessary. Heat was identified as a major opportunity for increasing renewable fuel; therefore the Renewable Heat Initiative (RHI) is proposed to come online in April 2011. This will provide a tariff on a per kWh_{TH} basis for heat generated from renewable sources.

It is important to note that to be considered renewable, fuels must be biogenically sourced, which is only partially true of SRF, as a significant contribution to the calorific value will be due to fossil fuel derived substances such as plastics that cannot yet be mechanically separated from the residual waste stream. Therefore in order to obtain the benefits outlined above, SRF must be analysed in order to determine the biogenic content. Two methods are commonly used for this analysis (Severin et al., 2010): manual separation method (MSM) and selective dissolution method (SDM). The first of these, as the name suggests involves manually sorting the waste into 14 categories. The second involves placing samples in acids, which will dissolve biogenic carbon more readily than fossilised carbon, which can be recovered gravimetrically. The second method is obviously faster and more reliable; however, it would require SRF producers to have a laboratory with technically trained staff.

7.3. Current and planned SRF production and use in the UK

Current SRF production was determined by a review of WDAs waste statistics, most of which was available from the Defra website. Any plants noted as producing SRF were then contacted to find out their annual production and quoted calorific value. Where this information was not available assumptions were made, based on the average from plants that

did reply and values reported in the literature. In the UK SRF is used in cement manufacture, power generation, advanced thermal treatment and on large industrial sites. The largest companies in each of these fields were contacted and asked whether and to what extent they currently use SRF, whether they intended to increase or decrease use in the future, and what they considered drivers and barriers to using SRF.

Cement Industry

The cement industry is currently the main sector utilising SRF at approximately 307,000 t yr^{-1} of a total of 450,000t yr^{-1}. Three companies dominate the manufacture of cement in the UK: CEMEX, Hanson and Lafarge, all of which currently use SRF in at least one of their kilns. Buxton Lime and Cement is the fourth largest, but has only one site in Derbyshire.

CEMEX has a 25% market share of the UK cement industry and currently uses 130,000 t yr^{-1} of SRF, called Climafuel, at its two kilns in Rugby and South Ferriby. The Rugby plant uses 100,000 t yr^{-1}, which represents 30% of the solid fuel input at the kiln. The South Ferriby kiln uses 30,000 t yr^{-1}. The SRF is sourced from a variety of locations including: approximately 18,000 t yr^{-1} from the Shanks Frog Island MBT plant in east London; 30,000 t yr^{-1} from the Materials and Recovery Energy Centre in Neath Port Talbot; 20,000 t yr^{-1} (recently increased from 12,000 t yr^{-1}) from Orchid Environmental MHT plant in Huyton, Merseyside; and the remaining 62,000 t yr^{-1} from thirty smaller companies including Premier Waste and Mid UK (CEMEX, 2009, personal communication).

CEMEX has three main drivers for the use of SRF. The first is the reduced cost compared to coal, which can be substantial when considering coal accounts for a third of total costs. Companies can actually command a gate fee of around £40-50 per tonne SRF (Archer et al., 2005, Defra, 2008c), while the current cost of coal is approximately US $75 per tonne (Blas, 2009). The second reason is the reduced CO_2 emissions which CEMEX estimate to be 1.5 tonnes of CO_2 per tonne of SRF. The last reason is the reduced NO_X emissions. The barriers to CEMEX's use of SRF include capital investment costs, which are estimated to be around £26m, negative public opinion and permitting issues with the Environment Agency.

CEMEX plans to build an MBT plant in Rugby that will process 300,000 t yr^{-1} of MSW and commercial and industrial waste (CIW). This will be able to produce approximately 150,000 t yr^{-1} of SRF by 2011, when the plant will be fully operational, for use at the local

Rugby kiln. Despite the closure of their Barrington plant/kiln last year, CEMEX would like to increase the use of SRF at its two kilns to 400,000 t yr^{-1} within the next eighteen months. Taking into account the current supply of 130,000 t yr^{-1} and the planned 150,000 t yr^{-1} from the Rugby MBT plant, this leaves an additional demand of 220,000 t yr^{-1} of SRF in the next eighteen months.

Hanson (formerly Castle Cement) currently uses approximately 167,000 t yr^{-1} of SRF sourced from three locations: 35,000 t yr^{-1} from Biffa's Leicester Ball Mill MBT plant; 75,000 t yr^{-1} from Shanks Jenkins Lane MBT plant in east London; and approximately 57,000 t yr^{-1}, assuming 18,000 t yr^{-1} goes to CEMEX (2009, personal communication) from Shanks Frog Island MBT plant in east London. The SRF is sent to Hanson's sister company SRM in Ketton, Rutland, where it is blended to specification, shredded and ground to a particle size of 20mm to facilitate complete combustion. The final product is called Profuel and 70,000 – 100,000 t yr^{-1} are used at the Ketton kiln and 35,000 – 70,000 t yr^{-1} is used at the Padeswood kiln in Flintshire (McKelvie, 2008). Unfortunately SRM were not able to comment on Hanson's future demand for SRF as it is considered commercially sensitive, but due to the recent reduction in output 'to a minimum' at the Padeswood kiln, because of the continuing downturn in the construction industry (BBC, 2009) and the fact that Hanson currently uses a considerable amount of SRF, it is unlikely that there will be additional demand in the near future.

Lafarge is currently the UK's largest cement operator. It is using approximately 10,000 t yr^{-1} of SRF from Shanks Locharmoss MBT plant in Dumfries and Galloway at the Dunbar kiln near Edinburgh. The SRF is procured through Lafarge's subsidiary company Glacier. Unfortunately Glacier did not comment on Lafarge's future demand for SRF. However, due to the economic downturn, Lafarge have recently put plans to build a cement kiln in Westbury on hold. This was due to receive 30,000 t yr^{-1} of SRF from the Hills Group/Entsorga MBT facility in Westbury. Therefore it could be concluded that there is no additional demand for SRF from Lafarge in the near future.

At present Buxton Lime and Cement do not use SRF at the Derbyshire kiln due to the lack of investment capital required as a result of the recession. They are looking to procure up to 40,000 t yr^{-1} of SRF in the future due to the reduced financial cost and lower GHG emissions of SRF compared to coal. Before utilising SRF they would have to undergo a lengthy process

of applications and trials required by the Environment Agency (Buxton Lime & Cement, 2009, personal communication).

Thus the overall additional demand for SRF from the cement industry is calculated to be approximately 260,000 t yr^{-1}. The size of the SRF market for cement manufacture is thus 717,000t yr^{-1} in the UK:

307,000 t yr^{-1} (amount currently used)

+ 150,000 t yr^{-1} (amount that will be used from planned Rugby MBT plant)

+ 260,000 t yr^{-1} (estimated additional demand from this study)

This is greater than previous estimates by the Resource Recovery Forum (RRF) up to 350,000 t yr^{-1} and (Archer et al., 2005) up to 500,000 t yr^{-1}, which assumed 10% fuel substitution by SRF.

Power Generation companies

The UK power generation industry is dominated by six companies: Scottish and Southern Energy, E.ON, Centrica, ScottishPower, RWE npower and EDF Energy.

Scottish and Southern Energy is the only power generation company currently using SRF. This is through their acquisition of Slough Heat and Power, including a CHP plant, in January 2008 for £49.25m. The plant utilises approximately 80,000 t yr^{-1} of SRF, which is produced onsite and termed Fibre Fuel. They would like to increase the amount by 40,000 t yr^{-1}. Their future plans also include a WID compliant multi-fuel CHP facility at Ferrybridge power station, Yorkshire, which will use a range of fuel sources including biomass, wood products and SRF. This facility could potentially use up to 500,000 t yr^{-1} of SRF. Further to this they have various proposed/planned multi-fuel projects due for completion by 2013, which will also be WID compliant and use approximately 2,500,000 t yr^{-1} of SRF. Thus the total additional demand from Scottish and Southern Energy is 3,040,000 t yr^{-1} of SRF by 2013. The drivers for Scottish and Southern Energy to use SRF include its low cost, price stability, ROC's availability, greenhouse gas emissions reductions, green PR benefits and various other legislative benefits. At present they do not see any barriers to the use of SRF.

E.ON does not use any SRF at the moment, but are looking into the use of SRF in separate facilities. These bespoke projects are at an early stage and greater detail will not be revealed until they are further developed.

Centrica's renewables division is principally an offshore wind developer and does not have any biomass and energy from waste projects. If Centrica were to consider using SRF the key issues would be cost, calorific value and impact on renewable benefits (ROCs) for the generation plant as a whole, versus other types of waste feedstock such as MSW and CIW (Centrica, 2009, personal communication).

Scottish Power, RWE npower and EDF Energy did not comment on their future demand for SRF. At present they do not use any SRF and it seems unlikely that they will in the future, as there have been no reports of them expressing an interest in SRF and they do not mention SRF on their renewables websites.

Overall the additional demand for SRF from power generation companies is at least 3,040,000 t yr^{-1} by 2013. This is in line with conclusions by (Archer et al., 2005) who suggested that allowing ROCs for the biomass fraction of SRF, will cause the power industry to embrace SRF.

Advanced thermal treatment companies

Advanced Thermal Treatment (ATT) companies currently use approximately 63,000 t yr^{-1} of SRF. Companies that are currently using, that have plans to use or have expressed an interest in using SRF are Energos (gasification), Scotgen (gasification), Biossence (gasification) and Graveson Energy Management (pyrolysis).

At the time of the interview, Energos were using approximatley 30,000 t yr^{-1} of SRF at their gasification plant on the Isle of Wight, which is sourced from Biffa/Island waste plant onsite. Another Energos gasification plant is planned to be built by October 2011 in Sinfin Lane, Derby, which will utilise 130,000 t yr^{-1} of SRF from the onsite Entsorga MBT facility. Energos have a further five UK plants with planning consent in Newport, Irvine, Lincolnshire, Knowsley and Doncaster, which will have a combined processing capacity of around 480,000 t yr^{-1} by 2012 of residual waste. Further to this another two plants are being considered by planners in Bristol and Londonderry that will have a combined processing

capacity of around 90,000 t yr^{-1}. In addition a further nine plants are being planned for the UK in collaboration with Biogen Power, who are also working in partnership with Energos for the Newport, Irvine and Doncaster plants. This gives a total additional processing capacity of at least 570,000 t yr^{-1} of residual waste. Energos are interested in procuring further contracts for SRF but are equally interested in contracts for untreated MSW or CIW. The decision on what fuel to use is based on economics and localised market conditions, such as transport costs, site criteria, and heat sales, for example Energos would not be interested in SRF if sources of MSW or CIW could be found nearer to the plant. A realistic estimate for total additional demand from Energos is at least 285,000 t yr^{-1} of SRF. Energos has many drivers for the use of SRF, compared to MSW or CIW. These include the higher calorific value, and thus greater energy revenue per tonne; and homogeneity, which results in more efficient plant operation. They also considered barriers to the use of SRF, compared to MSW or CIW. If the SRF is overly dried, this may lead to a CV that is too high, which limits throughput. Also there could potentially be reduced gate fees from taking SRF rather than MSW or CIW. It should be noted that since the interview was done the only plant that was in operation, on the Isle of Wight was shut down by the Environment Agency, due to high levels of dioxin emissions (Gala, 2010). The emissions have been attributed to a faulty filter, which is a result of the fact that the plant was retrofit on an existing incineration site, rather than a whole new development. However, it could be bad news for the other plants that were planned, as it could heighten public concern. Due to the recent recession, it is also likely that financial difficulties will delay bringing these facilities online.

Scotgen currently uses a minimum of 15,000 t yr^{-1} of SRF at its gasification plant in Dargavel, Dumfries sourced from Shanks MBT plant in Locharmoss, Dumfries and Galloway. This gasification plant is not currently at full capacity, but when the third production line becomes operational an additional 10,000 t yr^{-1} of SRF may be needed. The Scotgen plant uses Ascot Environmental's gasification technology; this technology will also be used by Cyclamax. Cyclamax are a resource park development company who are planning to use the technology at Avonmouth, whilst also having planning applications in for plants in Chesterfield and Derby, but these plants will be using segregated CIW rather than SRF (Scotgen, 2009, personal communication).

Biossence have a number of planned projects that will use SRF to generate electricity using a proprietary gasification technology. A joint venture between Biossence and New Earth Energy created the company Mersey Green Solution. Mersey Green plan to build on two sites at Widnes Waterfront and Hooton Park. The Widnes site will include an MBT plant that will produce approximately 150,000 t yr^{-1} of SRF. While the Hooton Park site will also use an MBT-like process to produce an estimated 150,000 t yr^{-1} of SRF. This SRF will be utilised at the Hooton Park site through a gasification plant.

Biossence have two additional projects that will utilise SRF, from external suppliers. In April 2009 Biossence purchased the East London Sustainable Energy Facility from Novera Energy for £1.25m. This will be located on the Ford Motor Company site at Dagenham, become operational in early 2012 and be able to produce 16MWe, which will be used by Ford. This plant will require up to 90,000 t yr^{-1} of SRF, which is planned to be obtained from the nearby Shanks MBT plant at Frog Island. SRF from this site is currently used by the cement industry; therefore there will be additional demand for SRF due to this. The final project is for a 12MWe gasification plant at Polegate, East Sussex. This is planned to be operational by the end of 2012 and will use up to 95,000 t yr^{-1} of recovered wood and some SRF. As most of the fuel will be recovered wood, a conservative estimate for SRF demand by this facility is 19,000t yr^{-1} (20% of total fuel). This gives a total additional demand from Biossence of approximately 109,000 t yr^{-1} of SRF. Biossence main driver for use of SRF is the availability of double ROCs, while the main barrier is the lack of availability of medium to long term contracts for the supply of SRF (Biossence, 2009, personal communication).

Graveson Energy Management (GEM) currently uses 18,000t yr^{-1} SRF at their pyrolysis plant, Scarborough Power, in Seamer Carr. The SRF is sourced from the onsite Wastec MBT like plant. Unfortunately GEM did not comment on their future demand for SRF. Interestingly plans to utilise the heat from this plant in addition to power generation have recently been put on hold due to unacceptable financial risk (Reynolds, 2009).

Thus although it may appear that ATT companies, i.e. Energos, Scotgen and Biossence, have an additional demand of at least 404,000t yr^{-1} SRF, it will be interesting to see whether all of these projects go ahead, and how successful they are, in light of the situations on the Isle of Wight and in Scarborough.

Industrial Sites

There are two industrial sites that are planning to use SRF, Ineos Chlor and Ince Resource Recovery Park. In addition the paper industry has been identified by previous reports as a possible candidate for SRF use.

Ineos Chlor are one of the UK's biggest gas customers using around 0.6% of the total UK gas demand – equivalent to a city the size of Liverpool. Ineos Chlor is planning to build a dedicated SRF burning CHP plant in Runcorn, Cheshire, which will provide heat and power (~100MW) for the neighbouring Ineos chemical works, 20% of the site's total energy demand. This will be done in two phases. Phase one will see Keppel Seghers build a CHP plant capable of treating up to 420,000 t yr^{-1} of SRF. Approximately 275,000 t yr^{-1} of SRF will be sourced from five Viridor/Laing MBT facilities that are being built as part of the Greater Manchester Waste Disposal Authority's (GMWDA) Private finance initiative (PFI) contract. The remaining SRF will be supplied by Viridor, possibly from their proposed MBT plant at Lostock Gralam, Northwich, which could be built as part of Cheshire's PFI. Viridor are one of two bidders that have been shortlisted for Cheshire's PFI contract. Phase one should be completed by 2013. The second phase of the CHP will be constructed when further contracts for SRF can be secured from other WDAs in the North West region. In total 750,000 t yr^{-1} of SRF will be required for the whole project; therefore an additional 330,000 t yr^{-1} of SRF is needed by Ineos Chlor.

Peel Environmental was recently given planning permission to build a 95MWe dedicated SRF burning CHP at Ince in Cheshire (DECC, 2009b). The development, known as the Resource Recovery Park, will burn 600,000 t yr^{-1} of SRF and supply electricity to adjacent industrial users, with the surplus being exported to the national grid (Peel Environmental, 2010). The development also includes a MBT plant with a treatment capacity of 100,000 t yr^{-1} of waste. It is therefore estimated that the MBT plant could produce approximately 50,000 t yr^{-1} of SRF. Peel Environmental state that this SRF will be used at the CHP plant, but the majority will be supplied from other MBT facilities in the region. Peel Environmental has an additional demand for SRF of approximately 550,000 t yr^{-1}.

The paper industry could potentially utilise between 300,000 t yr^{-1} and 600,000 t yr^{-1} of SRF in the UK. Currently no paper mills use any SRF in the UK and unfortunately no paper mills commented on their future demand for SRF.

It may be concluded that overall, industrial sites have an additional demand of at least 880,000 t yr^{-1} of SRF.

Thus the additional demand for SRF in the UK is 260,000 t yr^{-1} from the cement industry, 3,040,000 t yr^{-1} from power generation, 404,000 t yr^{-1} from advanced thermal treatments and 880,000 t yr^{-1} from other industrial sites, giving a total of at least 4,584,000 t yr^{-1}.

Total SRF production in the UK, including currently operating and plants in planning phase includes 518,000 tyr^{-1} yet to be allocated to a site for use. Additional demand indicates that all of this could be used, with potential for a further 4,066,000 t yr^{-1}. The main obstacle will be the time taken for plants to come online. If plants intending to use SRF take longer to come online, than those that produce it, there will be a surplus of SRF in the interim. The Environment Agency allows SRF to be stored under a waste management licence for a maximum of 3 years, at which point either a permit must be obtained for continued storage or a permit for disposal to landfill will be required (Environment Agency, 2008b). The export of SRF overseas is permitted, while there is a lack of markets in the UK, as long as proof can be provided that it is genuinely being used for energy recovery purposes.

Impact on biodegradable waste diversion

The waste composition study (Resource Futures, 2009), described in the introduction, found 28,340,112 tonnes of MSW was produced in 2006/07, of which 66.71% is biodegradable according to the Environment Agency definition. This means 18,905,669 tonnes of biodegradable waste. Waste types targeted for source-segregated collection into recycling or composting showed a large variation in capture rate. Garden was the highest at 75% while food was the least successful at only 1%. If we assume these capture rates are representative then the biodegradable fraction of the residual waste stream would be estimated 11,699,014 tonnes.

Through MBT and MHT treatment the mass will be reduced due to moisture and carbon loss in the biological treatment phase, the amount will depend on the processing. Entsorga's

mass balance indicates a loss of between 28 and 32%. The highest and lowest values of each of these would mean total BMW could be reduced to between 7,929,332t and 8,374,031t during processing. Thus, realistically SRF production could potentially account for just over half of the total residual biodegradable waste produced in the UK.

Contribution to energy generation

The information gathered through the interviews and desk based study were used to calculate energy generated from SRF using the following equations:

Calculation of the power generated & potential power generated by cement kilns from SRF

$E = C_{SRF}T_ex$ (equation 1)

E is energy generated in the cement kiln per year by SRF (MW_{Th})

C_{SRF} is calorific value of SRF (MJ/kg)

x is SRF utilised per year at cement kiln (kg)

T_e is thermal efficiency of the cement kiln (%).

$P = (E/3600)/h_{op}$ (equation 2)

P is thermal power generated in the cement kiln annually (MWth)

h_{op} is the number of hours the plant is operational for annually.

Thermal efficiency was taken to be 60% (Roberts and Spencer, 2009, personal communication) and h_{op} is estimated to be 7500 h. The calorific value of the various SRF products, are given in Appendix D. These were supplied by the relevant plant operators or else estimated based on an average determined from the other results, and the literature.

A complete table of the results is presented in Appendix D. Values calculated using this method, are superscripted with 1.

Calculation of the potential power generated by electricity generating power plants from SRF, using methodology adapted from (Lee et al., 2005).

$E_{SRF} = Y_{SRF} * E_I/Y_I$ (equation 3)

E_{SRF} is the electricity yield from SRF

$Y_{SRF} = T_{eSRF}C_{SRF}t_e$ (equation 4)

Y_{SRF} is the energy yield from SRF; t_e is the treatment efficiency of the MBT plant.

$Y_I = T_{eI}C_I$ (equation 5)

Y_I is the energy yield from incineration of residual BMW

E_I = electricity yield from incineration of residual BMW (taken to be 714 kWh/t)

$P_{SRF} = (E_{SRF}/1000)/h_{op}$ (equation 6)

P is the electrical power generated annually (MWe)

Again h_{op} was assumed to be 7500 h; treatment efficiency (t_e) was assumed to 50% (i.e. 50% of the incoming biodegradable fraction was converted into SRF); the calorific value of residual BMW was assumed to be 10MJ/kg; the thermal efficiency of incineration was assumed to be 25.4%; and the thermal efficiency of SRF in electricity production was assumed to be 40%.

The results calculated using this method in Appendix D, are superscripted with a 2. Results that are not superscripted with 1 or 2 were provided by the relevant end user, and are referenced accordingly.

Summary

Currently, approximately 450,000 t yr^{-1} SRF is being used in plants in the UK. The amount of power this is generating is approximately 17.2 MWe and 120.3 MWth. The additional amount of SRF predicted to be produced annually by 2013 is approximately 1,583,000 t. The potential power this will generate by planned plants in the UK 146.2 MWe and 240.7 MWth. Total annual SRF production by 2013 would then be around 2,033,000 t, potentially generating 163.4 MWe and 361 MWth. Lee et al. (2005) estimated that the maximum electrical yield in 2015, if all residual MSW in the UK was treated via MBT producing SRF, for use in electric power plants, assuming a thermal efficiency of 40%, as 22,500,000 MWh or 2,960 MWe if the power plants are assumed to run for 7500 hours per year.

The increased uptake of SRF will depend on various factors, firstly as has been shown, not all energy producers are interested in using SRF, and the use is not well established and may turn out to be less favourable than predicted. For example, the problems at the Isle of Wight gasification plant may see a drop in predicted future SRF demand. On the other hand, increased government incentives, such as the renewable heat initiative may increase interest in SRF use. Therefore, while SRF use was shown to have environmental benefits in the LCA presented in Chapter 3, in the current situation it will only be possible for approximately half of the total amount of biodegradable waste present in the residual MSW stream to be used in this capacity, without significant exports overseas. The alternative use for MBT outputs would be application to land. The results of the current trials to look at the application to land of MBT outputs as a soil conditioner may have an impact on SRF production. If these find that application to land is safe, this outlet may become more widespread, causing a decrease in SRF production, or if unsuccessful, may increase SRF production, as MBT plants aiming to produce a product for application to land may alter their biological treatment to produce SRF.

7.4. Marketability of compost from mixed residual waste

The application of land of outputs from MBT CLOs has few positive drivers for increased use and marketability. Quality protocols relating to application to land for both composted and digested wastes, PAS 100 and 110 respectively, both specify source segregation as a requirement for compliance. Further the EA has banned their use on land growing food or fodder crops, or any land likely to grow food or fodder crops in the future (Environment Agency, 2008a). Therefore their use is considered to be associated with the risk of causing a deterioration in the quality of soils, rather than improving them, as the replenishment of nutrients could be overshadowed by the presence of hazardous substances. Further The European Union has also identified lack of marketability as a barrier to widespread use of composts derived from mixed waste (European Commission, 2010). In the future the management of CLOs may fall under the proposed Soil Framework directive or the proposed Biowaste directive, neither of which are making much progress at present, increasing scope for wider use of CLOs in remediation projects, but at the moment, the market is virtually non-existent. As shown in Chapter 5 the marketability will be significantly hindered by the visual contamination of non-biodegradable waste, which would be difficult to market against other higher quality fertilisers unless it is significantly cheaper. This will be difficult as more

conventional composts, for example those produced from source segregated organics, are already cheap.

In spite of the difficulties, there are MBT processors that are aiming to produce a product for application to land (Archer et al., 2005) however, they have become frustrated with these restrictions, as it means their outputs must be landfilled. At least one operator in the UK that aimed to produce 'compost' product has altered the biological part of their treatment to produce a fuel as finding outlets became impossible and they had to landfill the outputs. One of the advantages of MBT is that it is relatively easy to alter the process to produce a different output by increasing or decreasing biological treatment times etc. (Godley and Read, 2010) thus if the legislation changes in the future, it may be possible for plants currently producing SRF to move towards application to land, if that market coincidently were to become saturated.

The EA has allowed for a strictly controlled trial of CLOs from mixed waste on land growing crops in central England. The trials are to be conducted over two years, however, preliminary results were presented at the Waste 2010 conference in Stratford-upon-Avon (Taylor et al., 2010). The results were positive, although they do specify that the recommendation is on crops whose edible part does not come into contact with the soils, such as wheat. It will be interesting to continue following the results of these trials to see whether the EA will relax the current restrictions on the use of CLOs. Their use in remediating contaminated sites has been shown to be beneficial (Farrell and Jones, 2009), and could provide a significant outlet under compliance with the British Standard 3882:2007 (BSI, 2007) although the presence of sharps will still be a safety concern where sites are accessible by the public. Expansion of non-food crops for biofuels is also likely to be a part of the future as the EU strives to become less dependent on imported fossil fuel (European Council, 2006). This could also provide a significant outlet for CLOs, as it removes the pathway to humans of ingesting crops that have taken up toxic elements and are more likely to be on private land with limited access. While applying CLOs to industrial crops decreases toxicity impacts, there is still a risk of pollutant emissions to atmosphere such as GHGs and acidifying pollutants. In the following chapter an experimental set-up is presented which aimed to measure gas emissions at the surface of soils where CLOs have been applied.

8. Application of CLOs to land

8.1. Introduction

Modern intensive agricultural practices have depleted soils of many of the nutrients required for plant growth (Gardiner and Miller, 2008). It would not be possible to continue to produce food at current rates without fertiliser addition. The most essential nutrient required is nitrogen, which can be synthetically manufactured. The uptake by plants of nitrogen in the most readily available form avoids losses to the atmosphere through the microbial processes of nitrification and denitrification (Gardiner and Miller, 2008, White, 1997). However, the fertilisers are most commonly produced by combining the hydrogen in natural gas with atmospheric N_2. The process requires significant energy input to break the strong bond of the N_2, accounting for approximately 94% of energy consumed by the fertiliser production industry (ADAS, 2009). The increasing cost of energy in combination with the depletion of natural gas resources (Shafiee and Topal, 2009) is causing the price of nitrogen fertilisers to become prohibitively expensive.

The second most essential soil nutrient is phosphorus. Although the P content of soils is not depleted, it is not present in a form that is readily available for uptake by plants, making the addition of fertilisers essential for food production. P fertilisers are most commonly derived from phosphate rock, a scarce resource with no synthetic substitute, which is expected to reach peak production in around 2030 (ADAS, 2009). The phosphorous content of available sources is also diminishing, while the concentration of other elements that can be detrimental to human health, especially cadmium, is increasing, therefore in order to produce phosphate fertilisers with safe levels of cadmium more energy is required. These factors are leading to a significant price increase. Organic waste contains nitrogen and phosphorus in readily available forms and can effectively replace mineral phosphate fertilisers and release the phosphates slowly, allowing long term growth improvement from a single application (Cordell, 2008).

Soil carbon content also appears to be lessening at a concerning rate. Bellamy et al. (2005) found that C concentration in soils in England and Wales decreased by approximately 0.6% yr^{-1} between 1978 and 2003. The application of CLOs could help to alleviate this situation. Increased plant growth due to improved soil fertility is also likely to increase absorption of

CO_2, and the majority of the carbon would be sequestered, unlike thermal waste treatments which release it.

Application of CLOs can also improve water-holding capacity in sandy soils and can assist with drainage in clay soils (WRAP, 2008) and prevent soil erosion. This is likely to become important in the future as the predicted impacts of climate change may cause longer drier summers and longer wetter winters in the UK.

Although there are many benefits to using organic waste in agriculture, there are also potential environmental burdens. The potential for the presence of pathogens, organic pollutants, heavy metals and other potentially toxic elements (PTEs) is of concern as there may be many pathways to receptors through biological and chemical reactions and physical transfer, presenting a risk to the environment and to human health through inhalation or ingestion (Smith, 2009, Ohandja et al., 2011 (In press)). These pathways include accumulation in soils, uptake in plants, runoff and leaching into waterways, and the formation of pollutant gases by soil-atmosphere interactions (Fowler et al., 2009). Regulations exist that set pollutant limit values for the first three pathways, however, soil-atmosphere gas exchanges have not been given the same amount of attention. These exchanges include some very important gases such as N_2O, a greenhouse gas with 296 times the radiative forcing potential of CO_2 that also contributes to depletion of the stratospheric ozone layer; and other nitrogen compounds that can lead to acidification and eutrophication through deposition. The formation of the other most common GHGs, CO_2 and CH_4 is also of concern (Liu and Greaver, 2009).

A recent study by (Defra, 2009) investigated the concentration of nutrients in different waste-derived soil conditioners including MBT CLOs and sewage sludge, in order to determine the mass required to achieve sufficient fertilisation. The nitrogen application rate used was 170 kg t^{-1}, which is the rate for long term sewage sludge studies, determined by nitrogen vulnerable zone limitations. It was found that 12.1 t ha^{-1} composted municipal wastes would be required compared to only 3.6 t ha^{-1} of sewage sludge. A greater mass applied will result in a corresponding increase in PTE concentration. Further, the large mass applied could restrict soil aeration by both compaction and the higher oxygen demand of composted MSW compared to sewage sludge. The unpredictable form of the nitrogen in CLOs also makes them more susceptible to nitrification and denitrification processes, leading

to the formation of nitrogen compound gases. This is more worrying for CLOs than sewage sludge as the former has a more heterogeneous incoming waste stream and is prone to significant temporal variations. Similarly the improvement of soil structure would require greater mass of compost per hectare than sewage sludge. However, significant cost savings could also be achieved for example a study on potato crops (WRAP, 2008) found a saving of £130 per hectare could be made by substituting mineral fertilisers with compost made from source segregated kitchen and garden waste.

The work presented in this chapter considers the potential for pollutant emissions to atmosphere where CLOs are applied to land as a soil conditioner and addresses the sixth objective. The flux chamber technique from The Centre for Ecology and Hydrology (CEH) was used to collect gas from soils with CLOs applied. The CEH method has been used for many years to test soils throughout Europe (Fowler et al., 2009) and is therefore well established. The gas samples were sent to an external laboratory for analysis by gas chromatography. The original aim of this part of the work was to determine GHG emissions of applying CLOs to land. Unfortunately due to unforeseen time constraints the results of the analysis were not able to provide significant indication of gas emission behaviour. However it is hoped that the methodology will provide a basis for a longer term experiment in the future.

8.2. Methodology

Samples

It was hoped that samples could be obtained from the same waste treatment facilities as used in the original analysis presented in Chapter 5. Unfortunately this was not the case. The Open University was still able to supply us with MBT samples, however, they were not the same as those used in the original analysis, as their contract with the other two plants had ended. The anaerobic digestion facility was unresponsive to our request for samples. This plant was originally built as part of the Defra demonstration programme, however, its contract with Defra expired during the time between the two experiments, and it is believed to be due to its new position as a private company, that it was no longer willing to provide samples. Finally the composting facility used in the original analysis said they could not allow us access due to health and safety regulations. It was noted that the member of staff who allowed us access previously was no longer working there, so perhaps this is why their

stance on the safety of access to the site had changed. Instead the following samples were used:

The first sample Figure 21 provided by the Open University, was taken from a recently opened MBT plant. The plant accepted mixed municipal solid waste which, after mechanical separation, was composted for seven weeks. As can be seen it was a very mixed waste, with significant non-biodegradable contamination, similar to sample F4 in the analysis of Chapter 5. The pH was measured using a Mettler Toledo FG2 pH meter, as close to neutral at 7.14. Table 20 provides a detailed analysis of the some other properties of this sample, as provided by the Open University.

Table 20: Sample properties (provided by suppliers)

Sample	**Dry matter (% fresh wt)**	**Loss on ignition (%DM)**	**N total (% DM)**	**C total (LOI/1.8)**	**C:N**
CLO (from MBT process)	75.9	60.3	1.2	33.5	26.9
Compost (from West London Compost)	72.0	55.1	0.2[a]	32.0[b]	Not available
Biosolids (from Anglian water)	39.2	43.2	2.47	24	9

[a] NH_4 plus NO_3
[b] LOI/1.72 (NB: LOI = loss on ignition)

Figure 21: MBT output sample

The second sample, Figure 22, was purchased from West London Compost, which takes in source-segregated kitchen and garden waste. Upon arrival at the site, the waste is shredded to homogenise the particle size. It is then put through a two-stage in-vessel composting process, which is operated in accordance with ABPR. Each stage operates for 10-14 weeks. The material is then moved to windrows, where it is regularly turned to mature for up to 8 weeks, to achieve the required specification. As can be seen, it is much more homogenous than the MBT output sample. Its pH was measured as 6.75. A full laboratory analysis of the sample was provided by the suppliers, and the most relevant parameters are shown in Table 20.

Figure 22: Compost sample from West London

The third sample, Figure 23, was sewage sludge provided by Anglian Water. Sewage sludge has been used in agriculture for more than 40 years (Water UK, 2008), currently absorbing approximately 73% of annual generation. Thus it was considered an appropriate sample for comparison with the CLO sample. The Sludge (use in agriculture) regulations (1989) (Statutory Instrument No. 1263, 1989), which enforce the EC Directive (86/278/EEC) (European Council, 1986), set limit values for some PTEs in soils that have had sludge applied. These do not set limits for organic contaminants, as no risk has been identified, although other member states have chosen to do this under the precautionary principle (Ohandja et al., 2011 (In press)). The sample was taken from the sewage treatment works on Cowley Road, Cambridge. The sewage, a mix from the local area and further afield, is passed through the CAMBI ® thermal hydrolysis process. It is then anaerobically digested at mesophilic temperature. The cake is then dewatered and analysed in accordance with the sewage sludge use in agriculture regulations. As can be seen this was in uniform pellets. Its pH was measured as 7.5. Further properties of this sample are shown in Table 20.

Figure 23: Sewage sludge sample

Upon receipt samples were stored in sealed plastic bags at below 4°C, in order to prevent further degradation prior to the experiment.

8.2.1. Flux chambers

Figure 24 shows the flux chamber set up. A 6m PVC 400mm diameter pipe was cut into segments of approximately 40cm. A PVC 400mm diameter flange was attached to 6 of these and sealed with a weatherproof flexible sealant.

Figure 24: Flux chamber apparatus

A square piece of aluminium sheeting, 480mm x 480mm x 3mm, with a 10mm diameter hole in the centre, was placed on top of the flanges, to make a lid.

The hole was filled with a 10mm diameter piece of PVC tubing, cut into lengths of approximately 800mm, reinforced with a silicon sealant. The end of the tubing was plugged with a three way stopcock.

At the sites, chambers were placed in the soil to a depth of 10cm. Where the ground was too hard or roots or rocks prevented positioning the chambers at the correct depth, a knife was used to loosen the earth and dig out any obstructions. pH, moisture and temperature were measured inside each chamber before sealing the lids.

The biosolids were placed in each of the chambers to a depth of around 3-5cm, using a broadcast method, as this was identified as the most common method practised (Stehfast and Bouwman, 2010, Dunfield et al., 1995).

As recommended (Carter and Gregorich, 2008) gas was collected time = zero , then the chambers sealed and further gas samples were collected after 30 minutes and 60 minutes. Double extractions were performed on a random number of occasions to determine the precision of the analysis. The testing protocol is given in Table 21.

Table 21: Number of samples collected at each site and time

pH	Time (mins)	Control (ambient air)	MBTCLO	Sewage sludge	Compost
4.56	0	2	1	1	1
	30	0	2	2	2
	60	0	1	1	1
5.5	0	2	1	2	1
	30	0	1	1	1
	60	0	2	1	2
6.7	0	1	2	1	2
	30	1	1	1	1
	60	1	1	2	1

The extraction was performed using a 60 ml syringe, which was pumped into a 1 l Tedlar bag on 20 occasions. Although this would have theoretically filled the bags beyond capacity, to 1.2 l, there was a small amount of leakage each time. The reliable storage time for Tedlar bags had previously been investigated by CEH in a comparison with other gas sample storage devices. They were deemed to store samples safely for up to 14 days. Although this is one of the shorter periods of storage compared to glass vials (1 month), or newer flexfoil bags (at least 92 days), the samples were couriered to the analysis laboratory within 48 hours of the collection, so 14 days storage was ample for this work.

Sample Collection Sites:

The chambers were placed at three different sites around the Silwood Park campus of Imperial College (Figure 25) chosen for the variation in vegetation. Moisture content at each site was measured using an SM300 soil moisture and temperature sensor, with a HH2 moisture meter, from Delta-T and pH measured using a Mettler Toledo FG2 pH meter.

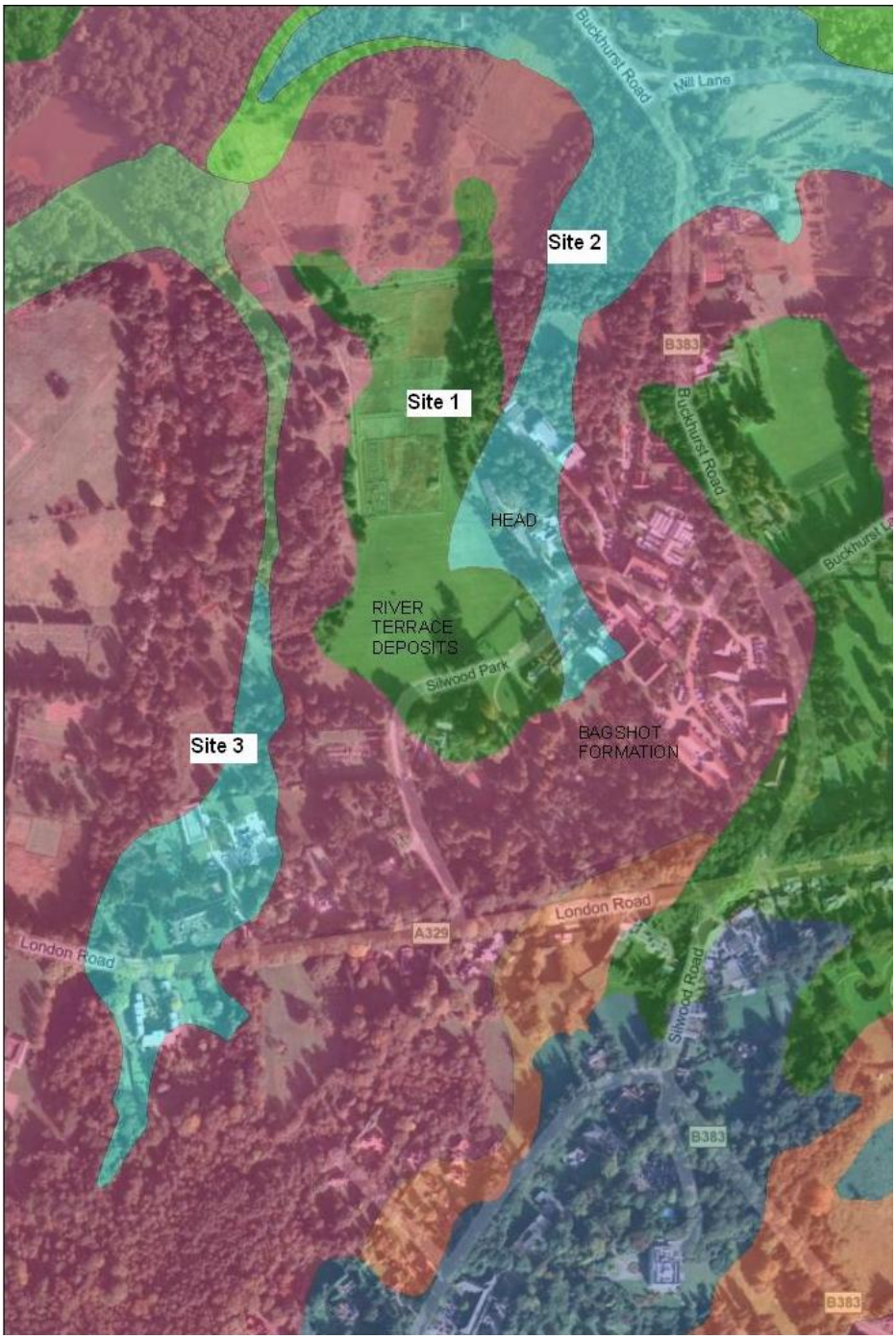


Figure 25: Map of three testing sites at Silwood Park

The first site, Figure 26, known as Silwood Bottom, is a cultivated field supporting a rich flora of ruderal arable weeds, conserved by annual ploughing (Crawley, 2005). The soil was identified as a silty loam, using the texture by feel flow diagram analysis (Thien, 1979). The pH was measured as approximately 6.7, the moisture content ranged between 4.0 and 7.8%. The sampling at this site was performed on Wednesday 1st September 2010, between 1400 and 1600, when the average temperature was 14.5°C.

Figure 26: Picture of site 1. Samples were collected near the bottom right hand corner of the photo

The second site, Figure 27 was in a young naturally regenerated oak woodland (Crawley, 2005). A layer of decaying leaves was covering the soil. The leaves were swept away before placing the CLOs on the earth. The soil was identified as sandy loam (Thien, 1979). The pH was measured as 4.56; the moisture content ranged between 4.5 and 10.7% with mean of 6.9%. The sampling was done on Thursday 2nd September 2010 between 1200 and 1400, on which the average temperature was 15.9°C.

Figure 27: Site 2

The third site, shown in Figure 28, was a grassland, bordered by trees, but these were not overshadowing the sampling site. The soil was covered with grasses and was identified as silty loam (Thien, 1979). The pH at this site was measured as 5.67 and the mean moisture level was 6.2%. The testing was done on Thursday 2nd September 2010 between 1500 and 1700, when the average temperature was 15.9°C.

Figure 28: Site 3

Gases from the MBT output and compost were also collected after being in place for two weeks at site 1, to see what effect the gas exchange would have with a longer time to diffuse into the soil below.

8.3. Results

The laboratory provided measurements for 8 different gases: methane, carbon dioxide, nitrogen, oxygen, hydrogen, ethylene, ethane and acetylene.

For all gases except carbon dioxide, nitrogen and oxygen the concentrations of the gas were below the limits of detection of the instrument, for each sample, over the hour. For methane this was < 0.1%, hydrogen < 20 ppm, and for ethylene, ethane, and acetylene < 5 ppm. The result for methane was in line with the expectation that application to land of outputs would prevent the formation of this gas, as oxygen inhibits the growth of methanogenic bacteria (Christensen, 1996). Although other studies have indicated that nitrogen enrichment of soils leads to an increase in methane formation and decrease in methane uptake (Liu and Greaver, 2009) these effects would occur over a longer period of time, and so would become evident at later sampling dates when the CLOs and soils had started to mix. Other factors can influence the results, such as excess moisture content (Kanno et al., 1997, Dunfield et al., 1995).

At site 1, with pH 6.7, four chambers were placed; one remained empty and a different CLO was added to each of the other three. At time t = 0 the gas concentration in each chamber was measured to provide a background concentration.

The mean nitrogen concentration measured at time 0 was 79.85% with standard deviation 0.4. Figure 29a shows the measured nitrogen values at 30 and 60 minutes. As can be seen the measured values fall within the 95% confidence limits of the mean, indicating these values are not likely significantly different from ambient concentrations. However, at t = 60 minutes, as time increases, the measured concentration in the chamber containing sewage sludge lies outside of the 95% confidence range of the mean, indicating a potential variation from ambient concentrations.

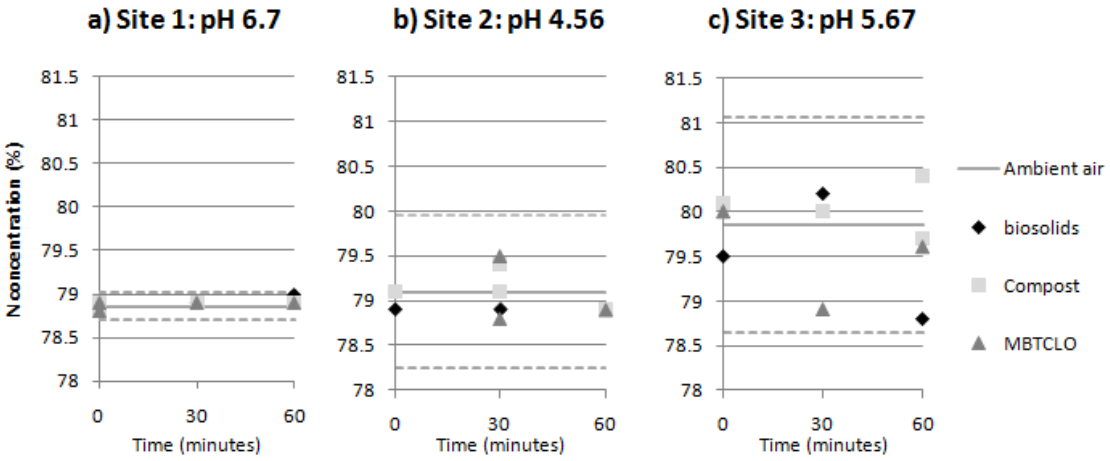


Figure 29: Measured nitrogen concentrations. Solid line indicates the mean, dashed line 3 standard deviations from the mean.

The mean oxygen concentration measured at t = 0 was 20.1%, with standard deviation 0.4. Figure 30a shows that almost all subsequent measurements lie within 95% distribution of the mean, indicating no significant variation in oxygen concentration. The measured concentration in the chamber containing sewage sludge lies outside of the range indicating possible significance. The combination between increased nitrogen and decreased oxygen shows possible nitrogen gas formation and warrants further sampling.

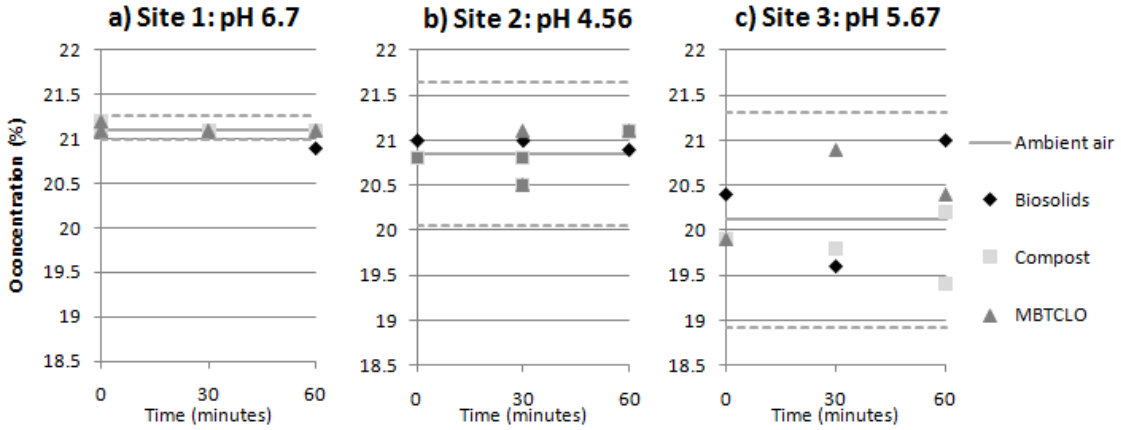


Figure 30: Oxygen concentrations measured at each site. The solid line indicates mean ambient concentration measured, and the dashed lines are 3 standard deviations from this.

At site 2, with pH 4.56, three chambers were located at the site, with the three samples introduced in the same way. Ambient air was measured at the start of the experiment, along with the air inside each chamber after the lid was finally sealed. The mean ambient nitrogen concentration was 79.4% with standard deviation 0.3. Figure 29b shows the results for

nitrogen at all times in the three chambers. The values all lie within 95% confidence limits of the mean indicating there is no significant variation in gas concentration. Similarly the mean background oxygen concentration was measured as 20.9% with standard deviation 0.3%. Figure 30b shows that all subsequent measurements lie within the 95% confidence limit of the mean, indicating no significant variation in oxygen concentration.

At site 3, with pH 5.67, again three chambers were positioned with the three different biosolid types. Two samples of ambient air, along with time t = 0 samples from each chamber were taken to determine background concentration. The mean nitrogen measured was 78.9%, with standard deviation 0.05%. Figure 29c shows the results and it can be seen that all results lie within 3 standard deviations of the mean, indicating there is no significant variation. Similarly for oxygen the mean background concentration was measured as 21.1% with standard deviation 0.05%, which is atmospheric concentration. Figure 30c shows all values lie within 95% confidence limits of the mean, indicating no significant variation in oxygen concentration with time.

The mean background carbon dioxide concentration was below the limits of detection at all sites and so is approximated to 0%. Figure 31 shows the variation in concentration at the three sites. As can be seen at site 1 there was no variation for CLO or compost, the sewage sludge showed no variation at 30 minutes, but had increased to 0.1% after 60 minutes, indicating minor degradation of the sample may have occurred.

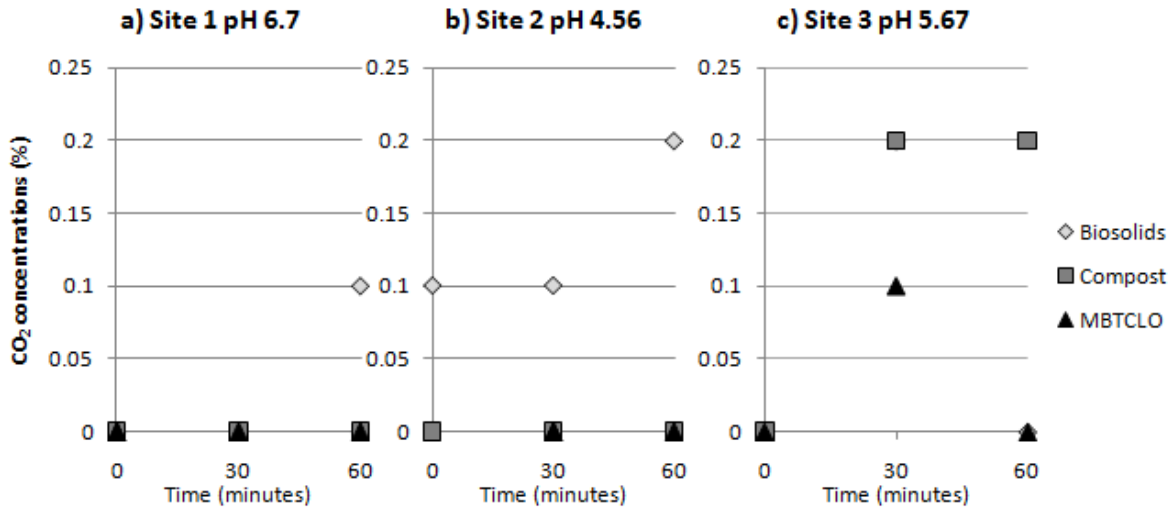


Figure 31: Measured CO_2 concentrations

At site 2, the mean background concentration was also approximated to 0, except when measured in the biosolids chamber. The concentration remained at 0 for compost and CLO throughout the measurement period, while the sewage sludge sample was still 0.1% at 30 minutes and increased to 0.2% after 60 minutes.

At site 3, the background concentration was again 0. For the CLO the concentration has increased to 0.1% after 30 minutes, but was 0 after 60 minutes. For the compost the concentration increased to 0.2% after 30 minutes and remained at this concentration after 60 minutes. The sewage sludge sample increased to 0.2% after 30 minutes, but was 0 after 60 minutes.

8.4. Discussion

The experimental work demonstrated the feasibility of the methodology but is of too short a duration to form any clear conclusions on gas evolution. Overall the sewage sludge sample appears to have the greatest influence on CO_2 concentration in these early stages. Although theoretically this type of biosolid should be the most biologically stable (Resource Futures, 2009), the very high moisture content makes it more likely to affect the soil below more readily. In the longer term, this renders the sludge more degradable by facilitating the transport of microbes and nutrients between microenvironments and dilutes the concentration of inhibitors (Christensen, 1996).

Greenhouse gas emissions are of particular concern, due to the predicted consequences of rising temperatures in the near future and the UK Government has set a legally binding target to reduce emissions to 80% of 1990 levels by 2050 (DECC, 2008). Soils contain nearly twice as much carbon as the atmosphere, but Bellamy et al. (2005) found that UK soils lost carbon at an estimated rate of 0.6 % per year between 1978 and 2003. The losses occurred independently of land use indicating a possible link with climate change. The lost carbon is likely to be due to several mechanisms, i.e. leaching as well as gas emissions, but the rate of loss is of concern. Addition of fertilisers to soils is considered as a carbon sink, because the resulting increased growth rates, will lead to increase CO_2 uptake. Nitrogen fertiliser addition also affects the CH_4 and N_2O fluxes of soils, and studies have indicated this may have a negative impact, offsetting the benefit from CO_2 uptake. Liu and Greaver (2009) compiled the results of experiments measuring soil gas fluxes and found that CH_4 emissions were increased and soil uptake of CH_4 from the atmosphere decreased. Similarly they found N_2O

emissions appeared to be stimulated by fertiliser addition, however another review (Chapuis-Lardy et al., 2007) indicated that soils may act as a net sink for N_2O. The conflicting results highlight the lack of understanding of mechanisms that produce and consume N_2O. It is an important area of research as N_2O not only contributes to climate change, but also ozone layer depletion. The IPCC reports that soils are the main source of this gas, estimated to emit 6.4Tg yr^{-1} from natural soils and 4.2Tg yr^{-1} from agricultural soils, with large uncertainties (Chapuis-Lardy et al., 2007).

Denitrification is the main process by which N_2O is consumed, and has been studied extensively using various methods including: inhibitor studies; stable isotope studies, by addition of N_2O to soils or investigating natural abundance; and microbiological approaches. Unfortunately all of these methods are intrusive and therefore fail to produce realistic representation of natural processes. Many experimental studies have measured a net negative N_2O flux; however, although several parameters that could affect consumption behaviour have been identified, including pH, moisture content, temperature and carbon concentration, results have been inconsistent. For example, Glatzel and Stahr (2001) found that low N content and poor aeration led to net N_2O consumption, while Rosenkranz et al. (2005) found net consumption in soils that had low N, but were well aerated and moist. Low availability of NO_3^{2-} is the only consistently identified factor contributing to consumption of N_2O by soils. The reason being that the reduction of N_2 occurs more readily in the presence of NO_3^{2-}, but N_2O will be reduced in its absence. Diffusion through soils has also been consistently identified as a contributing factor, with a longer residence time, often due to high moisture content, allowing increased reduction of N_2O to N_2. By measuring N_2O fluxes at the surface simultaneously with concentration in soil cores to a depth of approximately 10cm, moisture content has been shown to cause a significant delay between production of N_2O in the subsoil and flux measurements at the soil surface. Soil disturbances, especially agricultural practices, can release the trapped gas for example Clough et al. (2005) measured N_2O fluxes of 9-31% above background concentrations 1 minute after cultivation, but these had reduced to background fluxes within 2 hours. It is also possible the gas will have dissolved and leached away to be emitted elsewhere, or been taken up by plants and transpired. A more thorough understanding of the diffusion of gases formed in the subsoil is therefore also important. Changes in ambient pressure and temperature have also been investigated and shown to lead to movement of gases in soils. Studies have measured N_2O concentration in soil leachates,

but have not correlated these with concentrations in the soil profile. Readily available C has been identified as a limiting factor for this process (Clough et al., 2005), but studies have indicated that moisture content has a greater influence than C or N concentration.

8.5. Conclusions and future recommendations

The results presented here indicate that the impacts on soil atmosphere gas exchanges are negligible for CLOs and compost within the first hour of application. This is the time when significant N_2O fluxes have been measured in other experiments (Clough et al., 2005). A slight change in gas composition was detected at site 1 for the sewage sludge chamber. Similarly the carbon dioxide fluctuations were most pronounced in the sewage sludge chambers. The comparatively high moisture content of this sample would allow for more gas formation processes to occur, therefore in continuation of the experiment it would be interesting to make the moisture content of all the samples the same. However it is difficult to make conclusions with any certainty due to several factors.

Firstly the analysis results from the external laboratory were less sensitive than expected, based on results reported by other studies. Also they were unable to measure N_2O directly, which was one of the most important gases identified. Repeating the gas collection with an improved analysis, especially one that can measure N_2O directly is recommended for a future experiment, as continued experimental measurement of N_2O is important to increase understanding of the mechanisms that form the gas

The variation in soil pH at the three sites did not appear to contribute to the results; however, measurements taken after a few months, when greater mixing between the soils and CLOs has occurred may show a greater influence. A longer term experiment would also allow for greater investigation of methane fluxes which have shown contradictory fluxes in the literature.

This concludes the work focussing on obtaining UK based data relating to biodegradable outputs from MBT processes. The final objective focuses on investigating some of the limitations of applying LCA to waste management systems and is addressed in the following chapter.

9. Limitations of Applying LCA to waste management

9.1. Introduction

As explained in the main introduction, life cycle assessment involves collecting an inventory of the inputs and outputs at each stage of a product's life cycle and comparing the environmental burden based on a defined set of impact categories. The concept developed from modelling studies and energy audits of the late 1960s and early 1970s in both the UK and the USA, which attempted to assess the resource cost and environmental implications of different patterns of human behaviour (Curran, 1996). Studies conducted in the early 1970s were motivated by the oil crisis and focused on energy consumption. Through the 1970s these types of assessments continued to develop, but at a slower pace. A renewed interest emerged in the 1980s with the prominence of recycling, and has continued to develop as a tool for manufacturers to audit the environmental implications of their production practices, as customer awareness has demanded. The most important part of LCA analysis according to a survey of LCA practitioners is transparency of data. The study should be understandable by an educated non-expert of LCA and reproducible by an LCA expert (Bellekom et al., 2006).

More recently LCA has also become a decision making tool to help develop policies in relation to sustainability principles such as those of the UK government, according to which policies must be environmentally sustainable, without excessive economic and social burden (Defra, 2008b). The holistic approach LCA takes to impact assessment can be used in conjunction with more traditional decision-making tools such as cost benefit analysis. Tools such as cost benefit analysis remained popular because of their ability to address the balance between an environmentally beneficial option and economic or social burdens, with LCA expanding the boundaries of the decision-making to generate what is commonly referred to as a 'cradle to grave' approach.

As explained in Chapter 3 the 'end of life' part of an LCA often makes a significant contribution to total impacts. Thus using LCA techniques to assess the end of life is considered appropriate. Waste management systems for household waste, are often modelled separately to the rest of a product's life cycle because responsibility falls to end users, rather than producers. As mentioned in the introduction, the EU defines the waste hierarchy as a priority order for best practice in waste management, but goes on to state that deviation from

the hierarchy for specific waste types *is justified by life-cycle thinking on the overall impacts of the generation and management of such waste* (Parliament & Council of the European Union, 2008). The use of LCA to aid decision-making in the treatment of municipal waste faces some problems not encountered in its use to assess product life cycles. The functional unit in a product LCA is a single material, or set of materials with constant composition, whereas municipal waste is a heterogeneous, temporally and spatially varied mixture of different materials with the only common thread being they are no longer desired for their original purpose (Kirkpatrick, 1996). To produce a transparent and robust LCA it would be necessary to determine a complete inventory for every material that could potentially end up in the waste stream, however, most studies find it necessary to reduce these to a set of generic categories so the analysis can be done in a reasonable time without incurring excessive costs. The fact that extraction processes are only taken into account for offset benefits of recycling or energy recovery is also a limitation, as their impacts will usually be calculated as the average of any number of relevant processes, which as described in Chapter 4 can vary significantly. These are known as background systems, as their data is built into the model and cannot usually be altered by the user.

Table 22: Common limitations of waste management life cycle assessment tools

Limitations	Description	Relevance to WRATE
Spatial variation	Most LCAs for waste do not have function for geographical inputs, and other localised effects, therefore the proximity of pollutant releases to relevant receptors is not accounted for.	Yes
Background systems	Emissions from background systems such as power generation and fertiliser production are based on an average of various systems and often cannot be altered.	Mostly for some processes WRATE offers the user a selection, and it is possible for the user to alter some of these values, but this by no means applies to all the processes available in the model.
Linearity	The model can only compare different methods of treating the same mass and composition of waste for the entire time.	Yes

As explained in Chapter 3 the International Expert Group on LCA for Integrated Waste Management found limitations that did not allow for comparison between various software tools. Another study (Ekvall et al., 2007) identified various limitations which need to be acknowledged when employing LCA as a decision-making tool in waste management as outlined in Table 22, as well as the limitations relating to the determination of landfill

impacts, which were highlighted in Chapter 6. In light of these limitations there is a risk that non-experts will misinterpret the results, thereby not choosing the most environmentally beneficial process for their particular area. The limitations relating to spatial variance have been discussed in detail in Chapter 3, and it has been noted that these could be overcome by combining LCA with atmospheric dispersion modelling. Chapter 4 explored the limitations relating to background systems by showing that changing the electricity mix leads to significant changes in environmental benefits of some treatment processes.

In this final chapter the limitations relating to linearity are assessed. Linearity limitations largely relate to the fact that WRATE assesses a mass of waste with predefined composition, which cannot be altered within a single project. However, behaviour changes over time, which could lead to a significant alternation in waste composition, are important to consider, as many waste treatment processes, especially those for residual waste, have operational lifetimes of several decades, often accompanied by a high capital investment, which will only pay off over time, assuming the process continuously treats a set tonnage of waste annually. For example, a PFI contract will often be on the scale of 25-30 years. Evidence for this concern arises from the dramatic changes in consumer attitudes to waste that have been seen in the last 25 years. In this chapter two variations on this situation are considered:

Firstly what if the use of in-sink food disposal units were to become more widespread? Several potential drivers exist for this option including: mixing sewage with food waste has been shown to significantly increase methane yields in comparison with sewage sludge alone, for example Davidsson et al. (2007) found an increase in annual methane yield from 24 to 43 GWh. Vavilin et al. (2004) also found methane production enhanced by mixing food waste with an inoculum, such as sewage sludge. Economic incentives also exist to encourage energy generation from renewable sources. Anaerobic digestion attracts 2 renewable obligation certificates per kWh, and the benefits from renewable heat initiative may offer further economic incentive where the heat is also used. Small scale energy generation, which AD plants often fall into, are also eligible for feed-in tariffs. Further to this, the new coalition government has ambitious plans to increase AD as a technology and has money set aside to encourage projects (Defra, 2010a) therefore water companies can expect to receive significant financial incentives to upgrade treatment processes. Authorities that have introduced a

source-segregated food waste collection have met public opposition due to concerns of odour nuisance and vermin, particularly where they are accompanied by a reduction in residual waste collections from weekly to fortnightly, as was the case in Bristol. Insinkerators would separate food waste at source for anaerobic digestion, without the common concerns raised by residents.

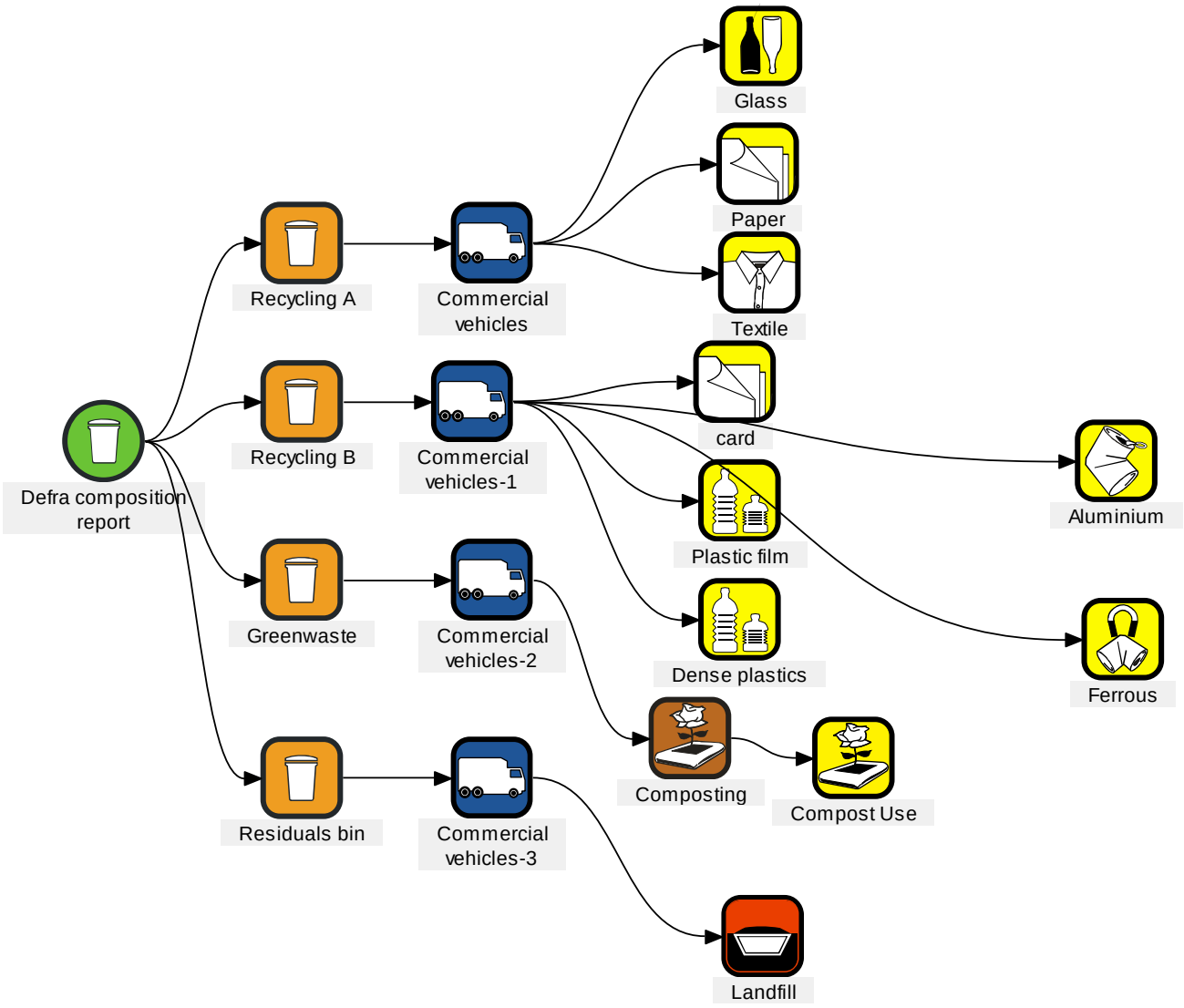
In the second case, the situation where home composting becomes very popular is considered. Although this is less likely, as an extreme example it was considered interesting. Therefore in this case all food and garden waste was placed in a home composting bin and applied to land privately, without any regulatory controls.

9.2. Methodology

The same 12 scenarios as described in Chapter 3 were used for this assessment. Figure 3 is reproduced here for ease of reference. Further detail on the input data can also be found in Appendix A.

Three cases were modelled for all twelve scenarios: the original case as defined in Chapter 3; the 'insinkerator' case, with no food waste entering the waste stream, reducing total waste to 120675 t per year; the home-composting case in which all food and garden waste is sent to a home-composting bin, and used as home compost. For comparison the diagram looks almost the same, except that the third branch no longer has a bin and vehicle, but goes straight into composting followed by compost use.

The results were generated as characterisation values for each of the 6 impact categories and copied into an excel spreadsheet. Graphs showing the total impacts for each scenario in all cases were produced.



Date 18/10/2010
Software Version 2.0.1.4
Database Version 2.0.1.4

9.3. Results

The removal of food waste from the residual waste stream led to system failure for the Global Renewables process, which requires a minimum biodegradable content of 25%. All other processes have lower minimum biodegradable acceptance restrictions.

As can be seen in Figure 32, for the landfill scenario GHG emissions the data point for the insinkerator case is more negative, indicating a reduction of greenhouse gas emissions compared to the base case. Several parts of the waste management system would contribute to this result. Firstly reduced mass of waste would lead to a reduction in the number of vehicle movements required for waste collection. Food waste would also contribute

significantly to landfill gas generation due to the rapidly degradable nature and high moisture content.

In the incineration scenario, the data point for the insinkerator case is more positive than the base case, indicating an increase in GHG emissions. This result is dominated by the fact that the reduced total mass of waste reduces the amount of energy generated from the incineration process and thus the benefit of offsetting fossil fuel use for electricity production. Other benefits such as reduced transport movements are overshadowed by this. As demonstrated in Chapter 4 this is highly dependent on the fuel used for electricity production, and the benefits would change to favour insinkerator use if this were low emission fuels.

For the MBT processes, GHG emissions were increased in the insinkerator case for Ecodeco, Herhof and Entsorga. The outputs from each of these processes are dominated by SRF, indicating that the benefit of offsetting fossil fuel use for electricity production is the overriding factor. For Haase, Arrowbio and VKW, the insinkerator case has a minor reduction in GHG emissions. Each of these processes produces stabilite, which is landfilled, therefore the reduced food waste, leads to a corresponding reduction in biodegradable waste to landfill, thereby reducing landfill gas generation. Little variation is seen between the two cases for the Bedminster, SRS and Linde scenarios. Bedminster and SRS both produce compost-like output for application to land. Therefore food waste does not have a significant impact on the GHG emissions from these processes. Linde unlike the other processes produces significant amounts of both SRF and stabilite to landfill, therefore the increase due to not being able to offset electricity production for fossil fuels and the reduction in landfill gas generation, appear to have balanced out.

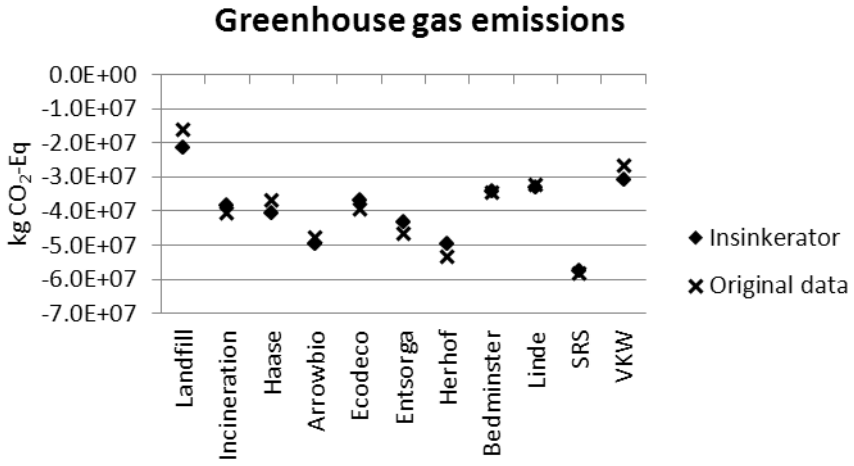


Figure 32: Modelled greenhouse gas emissions (kgCO_2 equivalent)

It is important to note that the WRATE modelling only considers impacts attributed to the waste management industry. By sending food waste to sewers its management becomes the responsibility of the water industry. Therefore the burdens and benefits of co-digesting food waste with sewage are not accounted for by WRATE. Another study by Evans (2007) found that the use of insinkerators would decrease GHG emissions by 168kg CO_2 per tonne of food waste. Adding this value to those generated by WRATE shown in Figure 33, makes the use of insinkerators reduce GHG emissions in all scenarios, including incineration. Thus the benefit of AD use which also produces energy offsetting the use of fossil fuels, now improves the results compared with incineration and SRF use. The Evans study assumes gas is used to generate energy, offsetting the use of fossil fuels, and the digestate outputs are applied to land, offsetting some fertiliser production. Therefore this result is a best case scenario, and may not occur in reality. The same issue is currently under investigation by WRc, and although the results are yet to be published, preliminary results were presented at the Waste 2008 conference (John Andrews, 2008, personal communication). The results in this case indicated that the GHG benefit was limited or non-existent due to the energy and embedded carbon required to install the units in a large number of households. A detailed study into the impacts of insinkerators is being conducted by other members of the research group.

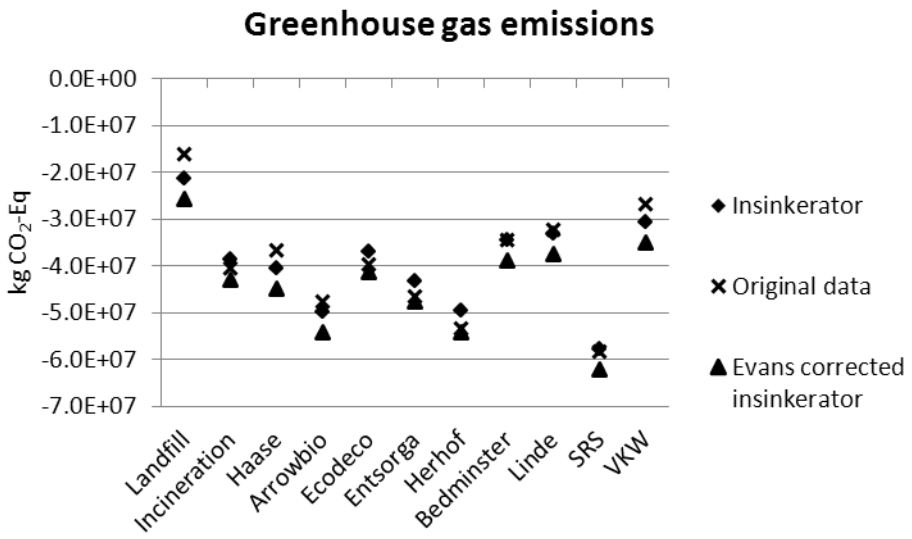


Figure 33: GHG emissions corrected to account for emissions attributed to the water industry

Figure 34 shows the modelled acidification impacts for the two cases. In the landfill scenario, emissions are slightly reduced by the use of insinkerators. This is likely to due to a combination of factors, including a reduction in vehicle movements, due to a reduction in overall mass of waste, and reduced landfill gas generation, due to the reduction in biodegradable waste landfilled.

In the incineration scenario, emissions of acidifying pollutants are also reduced in the insinkerator case, due to total reduction in waste combusted, and again reduced transport. For the MBT scenarios Haase, Arrowbio and VKW show a decrease in acidifying pollutant emissions with the use of insinkerators. These three processes send the majority of outputs to landfill, either as stabilite or reject. Therefore the removal of food waste from the system, would reduce the amount of biodegradable waste to landfill, and hence landfill gas generation. There is insignificant variation between the two cases for the Bedminster scenario, as was the situation for the GHG impacts, indicating food waste does not have a significant influence on emissions of acidifying pollutants from this process. All other MBT processes showed an increase in emissions with the use of insinkerators. For Ecodoco, Entsorga, Herhof and Linde, the majority of outputs are SRF. This fuel would produce lower levels of acidifying pollutants than incineration of untreated waste, due to the improved quality through the biological treatment. Fossil fuels would produce a lot more acidifying pollutants, therefore the reduced amount of energy produced, that would offset the use of

fossil fuels, has therefore increased emissions. In the case of SRS, some of the outputs are applied to land, and could therefore offset the use of fertilisers, which could release some acidifying pollutants, especially nitrogen compounds.

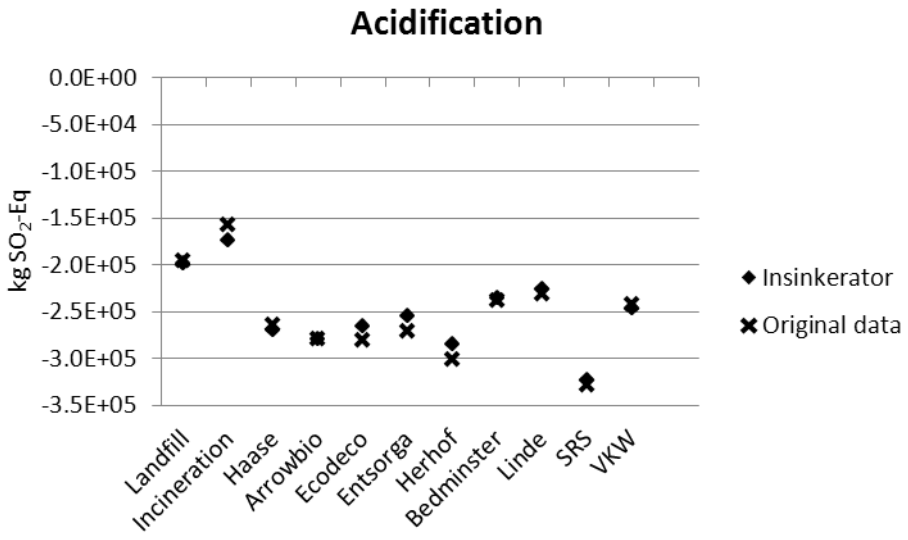


Figure 34: Modelled acidification impacts ($kgSO_2$ equivalent)

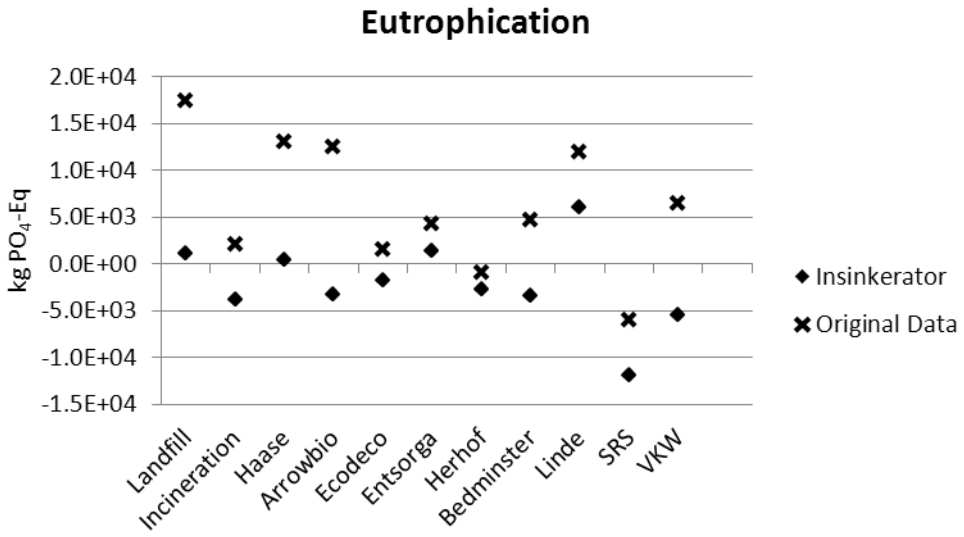


Figure 35: Modelled eutrophication impacts ($kgPO_4$ equivalents)

Eutrophication, shown in Figure 35, has the most significant change in impacts. The use of insinkerators shows a large reduction in the production of eutrophying pollutants. Food waste is a source of phosphorous and various nitrogen compounds, which contribute to eutrophication, therefore its absence greatly reduces the risk of these pollutants entering the

environment. The emission of eutrophying pollutants due to the co-digestion process, and subsequent application to land of the digestate is likely to be significant, therefore these results should be taken in conjunction with a separate assessment of the water treatment process. Unfortunately the other studies considered (Evans, 2007, Davidsson et al., 2007) only measured GHG emissions.

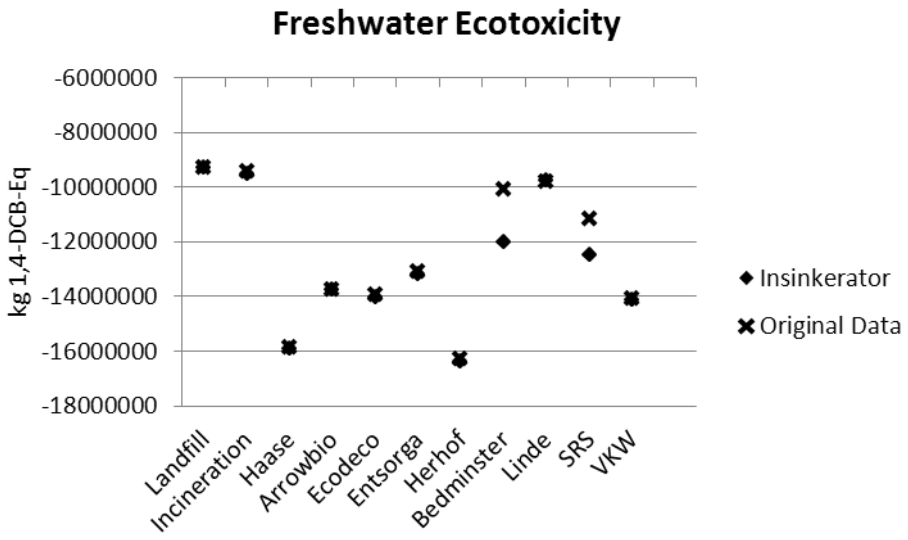


Figure 36: Modelled freshwater ecotoxicity impacts (kg 1,4-DCB - equivalents)

Freshwater ecotoxicity Figure 36 has an insignificant change with the removal of food waste, except for the Bedminster and SRS MBT processes. These are the two processes that produce low quality compost for application to land, opening up a pathway for pollutants to reach relevant receptors. Removing food waste has decreased the concentration of pollutants toxic to freshwater ecosystems, therefore the impacts are decreased. Again the application to land of digestate from the waste water treatment would contribute significantly to this category, however, these emissions are highly dependent on the presence of relevant receptors, and as long as its use is compliant with regulations, ecotoxicity impacts should be avoidable.

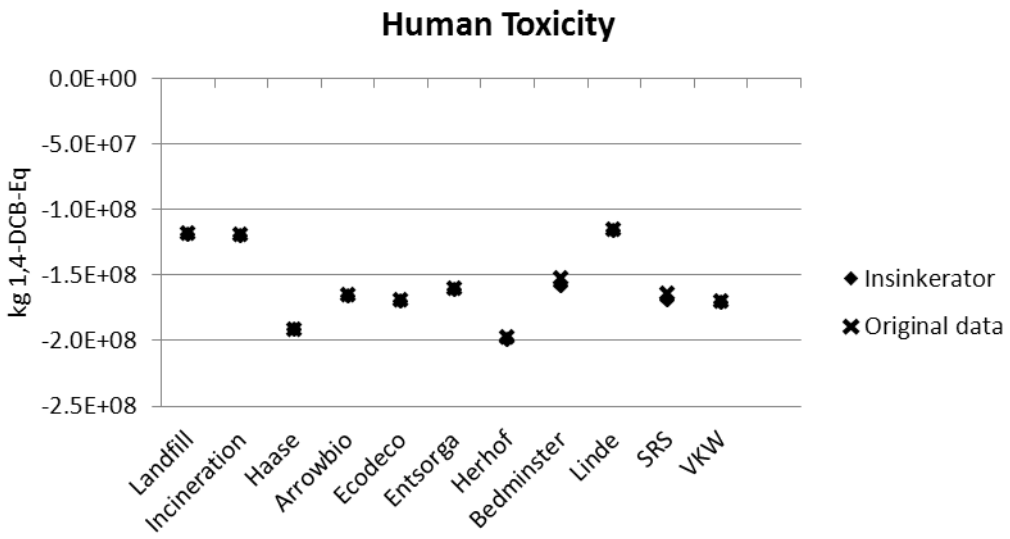


Figure 37: Modelled human toxicity impacts (kg 1,4-DCB equivalents)

There is no significant variation in human toxicity impacts (Figure 37) between the 2 scenarios; again the greatest change is in the 2 compost producing processes, Bedminster and SRS. Human toxicity impacts would similarly be exposure-related, and avoidable through careful use. The sewage sludge regulations, which have been used safely for approximately four decades in the UK, indicate that this should not be problematic. The addition of food waste to sewage sludge would only increase risks to health, due to increased likelihood of pathogen presence; however, compliance with ABPR, as in heating the digestate to the temperatures, should destroy pathogens present.

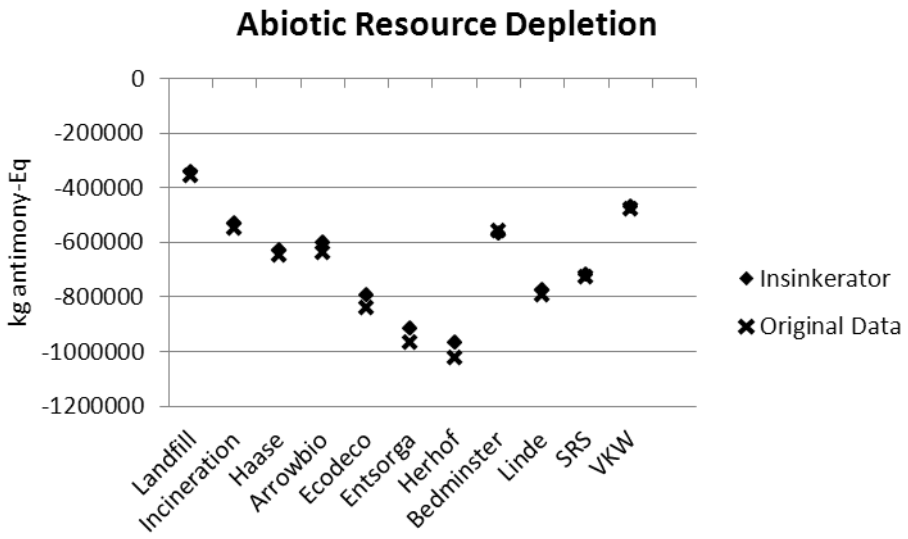


Figure 38: Modelled abiotic resource depletion impacts (kg antimony equivalent)

Although the depletion of abiotic resources impacts (Figure 38) do not vary significantly between the 2 cases, it is interesting to note that for the majority of scenarios the impacts are worse in the insinkerator case. Some of the resources considered in this impact category are fuels used to produce electricity including both fossil and nuclear. Therefore the reduced production of energy through removal of food waste, and subsequent reduction in offset of fossil fuel sources is likely to be the dominant factor in this result. The only process that showed an improvement in resource depletion with use of insinkerators was Bedminster. This process produces the greatest amount of CLO for application to land, nearly twice as much as SRS. Therefore this result may be related to the ability of this process to reduce synthetic fertiliser production.

Home-composting comparison

In this part of the modelling all kitchen and garden waste was assumed to be home composted. This led to system failures of all the MBT processes. The reasons cited for this were two fold, all processes were not able to accept a greater than 5% proportion of WEEE, and the percentage entering the process was increased to 5.7% by the removal of the organic fraction. The other, more expected reason was that the percentage of biodegradable waste was too low for the process to operate successfully. This however, was only given by Haase, Global Renewables and SRS. Further investigation of the process restrictions found that all other processes had a minimum organic requirement of 0 or 0.1%. This seems ridiculous as

other biodegradable waste types, especially paper and textiles, are higher in lignin and would degrade very slowly, not really being suited to composting and recalcitrant in an anaerobic environment.

The results presented (Figure 39) therefore only provide a comparison between the landfill and incineration waste management systems. In the landfill scenario GHG emissions were greatly reduced with home composting, due to a combination of increased diversion of biodegradable waste from landfill, and reduction in vehicle movements, as less waste requiring collection. For the incineration scenario, GHG emissions were significantly increased with the use of home-composting, which would be due to the reduced amount of energy produced, due to the loss of the high calorific garden waste fraction. This emphasises the dependence of the environmental benefits in the incineration scenario on its ability to offset energy generation from fossil fuels.

Acidification impacts are greatly increased with home composting for the landfill and incineration scenarios. This is likely to be related to the uncontrolled nature of home composting. Eutrophication impacts are also greatly increased with the use of home-composting in both scenarios. This would be due to the large amount of application to land of compost produced, which was the assumed final use of the product. Unlike large scale composting processes, the application to land of home composts is unregulated; therefore the likelihood of application in nitrogen vulnerable zones would be increased. Although it would be widespread use of small amounts of compost, rather than large amounts on a small area, therefore the risks maybe not be as concerning as they seem.

The freshwater toxicity impacts are reduced in the home composting case for both landfill and incineration scenarios. The removal of the putrescible fraction from landfills would cause a subsequent reduction in moisture content, which would also reduce the movement of potentially toxic elements through a landfill. Therefore it is unlikely these would leach into groundwater, or runoff into surface waters. Similarly the removal of the organic fraction would significantly reduce gas generation and thus the potential for emissions to atmosphere which could be deposited into waterways further away. There is an insignificant difference in the human toxicity impacts between the two cases for the landfill scenario. For the incineration scenario home-composting reduces human toxicity impacts. This is due to the reduction of total mass being incinerated, and therefore an overall reduction in emissions, in

conjunction with the removal of any potentially toxic elements in the organic fraction being present in emissions from the incineration process.

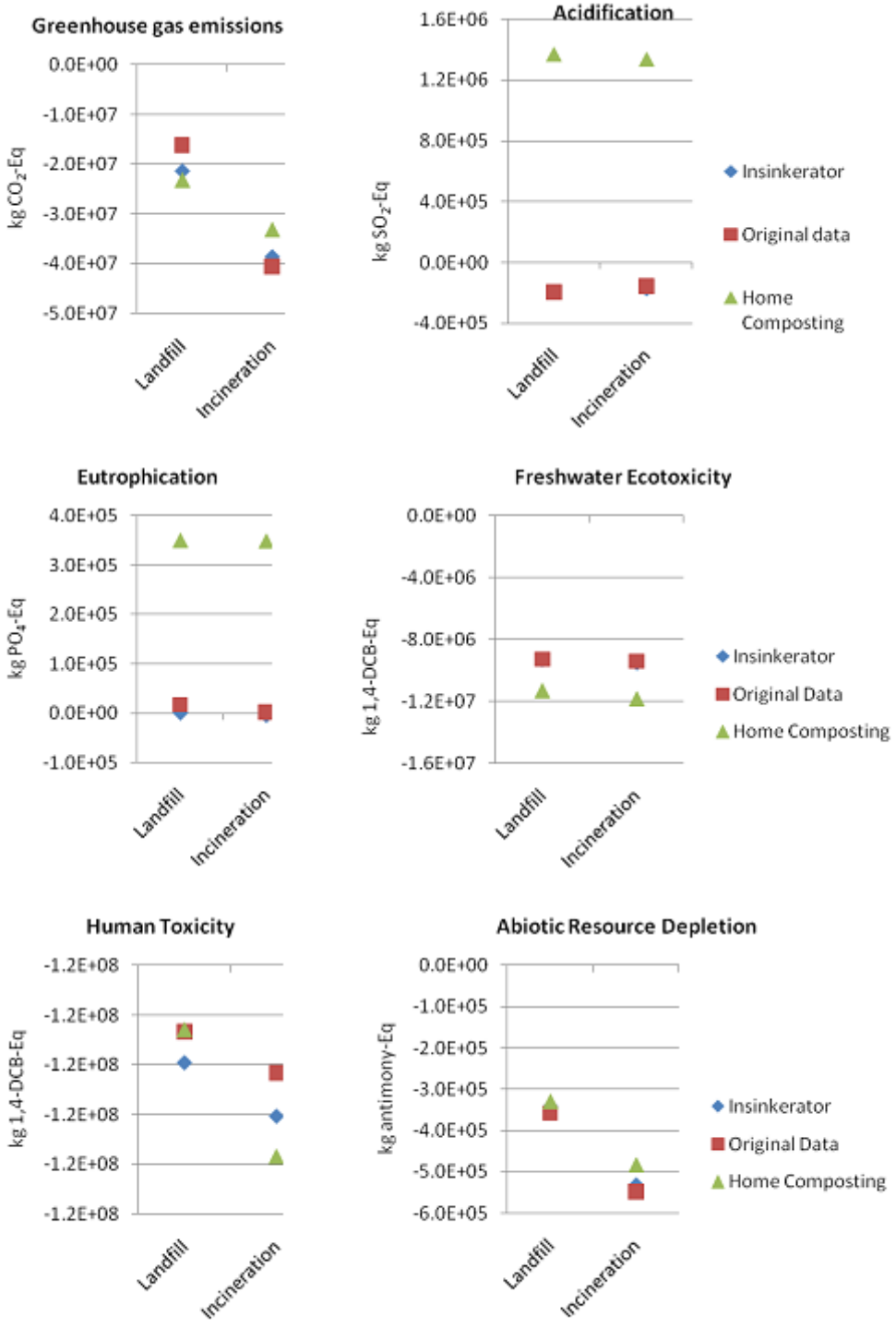


Figure 39: Home-composting case impacts

Resource depletion impacts are increased in the home-composting scenario. This is most likely due to the reduction of energy from waste, which takes away the opportunity to offset the use of fossil fuels for electricity production.

9.4. Discussion

The limitations described in this chapter indicate that using LCA on its own as a decision making tool for waste management systems will not necessarily indicate the most sustainable option over the long term. Although the limitations relating to geographical location could be amended by combining LCA modelling with an atmospheric dispersion model, the limitations relating to linearity and background systems are much more complicated. In Chapter 4 it was demonstrated that changing the electricity mix led to a significant decrease in the environmental benefits of recovering energy from waste. This is of concern as the UK electricity fuel mix is almost certain to change in the next few decades, which is the timescale required for many waste treatment facilities to be operating at capacity in order to be economically viable. The limitations relating to changes in human behaviour demonstrated in this chapter that could also impact the sustainability of certain waste treatment processes, in particular several of the MBT processes would not be able to operate with low levels of biodegradable waste.

Is it likely that behaviours will change significantly in the scale of decades being considered? Looking at the last decade as an indicator, significant changes in behaviour have occurred. Total household waste arisings showed a year on year increase up until 2000/01, but have stayed relatively stable since then. Source-segregated collections for household waste have significantly increased from a mere 6% in 1996/7 to the most recent rate of 39.7% in 2010 (Defra, 2010c). The success of these schemes relies on public participation in kerbside sorting, therefore it indicates an increased awareness of environmental issues, and willingness to participate in schemes to improve the environment in the majority of people. Although there are still a significant number of people who choose not to participate, a gradual increase in participation has been seen annually, and this trend is predicted to continue.

This begs the question, is LCA the best method for deciding on the most sustainable waste management system? Or is the problem that the concept of "waste" is evolving. In the introduction to this thesis the EU definition of waste was presented as it is stated in the

directive “any substance or object which the holder discards or intends or is required to discard”. However, this definition is not always clear and has led to many Rulings in the European Court of Justice (ECJ) (EIONET, 2009). A guidance document on interpreting the definition was developed in the UK shortly after the definition was first established, in 1994, however in light of the ECJ Rulings a consultation is underway in the UK to amend the guidance accordingly (Defra, 2010b). A framework has been agreed and study is underway at the Joint Research Centre in Seville to provide end of waste criteria for a selection of wastes. Thus the general definition of waste is not entirely clear. Other examples of the evolution of ‘waste’ include the recent publication of the PAS 110 for the use of digestate (Waste and Resources Action Programme, 2010), which allows compliant substances to no longer be classified as waste, and therefore available to use without complex waste handling regulations. However, SRF, cannot be considered a product until it is used, because until it is combusted, it may still end up in landfill, if a customer is not found within the 3 year storage allowance.

Under the concept of life cycle assessment, waste refers to the ‘end of life’ of a product. However, this is also open to interpretation as some products, when no longer suitable for their original purpose can be used in another context, rather than being disposed of, so should they really be classified as waste, subjecting their reuse to a complex set of regulations? ‘Life cycle’ is defined in ISO 14044 (British Standards Institute, 2006) as consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal, which would imply ‘end of life’ would continue to assess all subsequent uses of a product until it is released to the environment in an irretrievable form. Thus perhaps waste should only apply to materials which are no longer useful and need to be disposed of, rather than materials that are no longer useful for their intended purpose. Will the concept of ‘waste’ alter as increased environmental awareness begins to drive consumer decision-making? Perhaps a better way to manage waste, is through increased producer responsibility, so that a product’s end-of-life is considered at its point of manufacture. In fact within an economic system based on continuous growth, how can mutual sustainability of economy and the environment be achieved without a corresponding increasing waste generation, unless producer responsibility is extended to cover in some part the management of end of life of products? Increased producer responsibility has been a legislative tool for various aspects of waste management including the packaging waste

(Parliament & Council of the European Union, 1994), vehicles (Parliament & Council of the European Union, 2000a) waste electrical and electronic equipment (EEE) (Parliament & Council of the European Union, 2003a and b); and waste batteries and accumulators (Parliament & Council of the European Union, 2006a).

The problem with much of the producer responsibility legislation is that a lot of it pushes for increasing the recyclability of products. However, recycling is the third option on the waste hierarchy, according to which we should be focusing on waste prevention. In terms of biodegradable waste it is especially important.

Considering the paper and card fraction, which makes up over 20% of total municipal solid waste, it was explained that this is not infinitely recyclable as the fibres deteriorate and recycling is limited to at most 7 cycles. This is confounded by different types of paper being mixed together, different types of ink, some of which contain hazardous substances making them difficult to pre-treat for recycling. Production of energy from paper waste has been shown to have an environmental benefit due to the high calorific value, but offset against an electricity fuel mix with low level emissions, the benefits are reduced. Conversion to ethanol for use as vehicle fuel, or other chemical products has been investigated extensively, however, the conversion of cellulose to glucose has been found to be prohibitively expensive and thus unable to compete economically with starch based materials (Badger, 2002). The high lignin content of some paper/card products, especially newspaper (Palmisano and Barlaz, 1996) further confounds this option by inhibiting enzyme access to the cellulose substrate, making the process prohibitively long for commercial development. Cheaper genetically modified enzymes that can perform the degradation more rapidly have recently been developed reducing the cost, however, it is still considered unlikely that commercial scale facilities will be developed without financial backing from governments (Morris, 2007).

Prevention of waste paper as far as possible is the most sustainable option, and it is strange that more isn't being done to promote this. News is currently available on TV, radio, the internet and with the prevalence of portable internet access, such as smart phones allowing constant streaming of news feeds to read anywhere anytime. One could question why we continue to waste valuable energy resources printing the news on paper every day, and then try to force this low quality material through a recycling process? Junk mail is another area of waste prevention. There are various campaigns encouraging the reduction of this waste

stream, however, these are quite low-key and do not appear to have significant government support. For instance the royal mail offers an opt-out service unaddressed advertising material, however, it is not widely advertised and is used by only 0.7% of households. 15% of households have signed up for a better known service, the mailing preference service; however, the royal mail service is believed to be much more effective. An agreement between royal mail and the communication workers union which limited the amount of unaddressed mail the royal mail could deliver to 3 pieces per week was lifted in April 2010 allowing unlimited amounts of junk mail to be delivered. This is unfortunate, as this type of material not only contributes to waste, but is also problematic for litter as it is largely unwanted (Stop Junk Mail, 2010). A final area for preventing waste paper is in office management, where the prevalence of email and computer based work should have seen a significant fall in office paper use. Promoting paperless offices would be a good way of limiting paper waste.

It is of concern that emphasis has been placed on increasing recycling rates through weight-based targets, rather than reductions in waste generation, as prescribed by the hierarchy, as this has led to the development of paper reprocessing industry which now relies on waste paper for continued profit, thereby discouraging the prevention of this waste type. The idea of improving the quality of paper by using materials other than wood pulp, such as hemp or flax (van der Werf, 1994, McDonough and Braungart, 2002) has been put forward, as these would be higher quality and potentially reusable, avoiding the difficulties surrounding paper recycling. However, this idea is at an early stage and the impacts of widespread development of this industry for the UK have not yet been considered.

Food waste is another problem as obviously it can't be 'recycled' and although it can be treated and returned to land, it can lead to difficulties in composting, processing plants want food waste to make up only about 1/6 of the total mix with garden waste, to reduce odour and bioaerosol impacts. Anaerobic digestion has been identified as a best approach for treating food waste as it produces biogas for energy and digestate for soil replenishment (Defra, 2010a), however, this process has been shown to require careful segregation from contaminants, but to require the presence of other wastes (Banks, 2010). The process has also been found to be sensitive to temporal variations, requiring very careful management of the inputs, which could potentially lead to high reject rates.

Achieving widespread participation in source segregation food waste schemes is difficult due to the potential for odour nuisance and vermin. The fact that it can't be contaminated with plastics makes it difficult as people would prefer to keep the waste sealed to prevent odours. Corn or potato starch based plastics are the only solution to this, but they are not cheap, they cause confusion in plastics sorting and do not degrade at the same rate as the waste they contain. It is difficult to expect to spend money on expensive bags and segregate their waste. It might seem that this waste stream is not avoidable, as of course there are parts of foods, like fruit and vegetable peels which are inedible. However, the WRAP study (Ventour, 2008) found this only accounted for 19% of food waste. Over 80% could have been eaten, including 8% still in date at the time of disposal. The main reasons identified for so much waste are leftovers and misunderstood expiry and best before dates. The reduction of household food waste is one of the aims of the Courtauld commitment. The Co-operative introduced storage instructions on the packaging of their fresh produce, and stopped 'buy one get one free' offers, promoting half price offers instead. Sainsbury's have been trialling the provision of storage information both in store and on their website (WRAP, 2010). Over the period 2005-2009, phase 1 of the commitment, household food waste was reduced by 155,000 tonnes, and the second phase includes a target to reduce this even further (Lets Recycle, 2010a).

The segregated collection of gardening waste is generally one of the more successful processes, achieving a rate of 76% (Jones et al., 2008b). It is easier to deal with on its own as it removes the need for ABPR compliance, as well as being less likely to attract vermin. The fact that this waste type is only produced by people with gardeners, would make them more aware of the usefulness of compost, and more willing to participate, especially if the product were returned.

Closed loop, cradle to cradle, circular economy

McDonough and Braungart (2002) published the landmark book Cradle to Cradle, introducing the idea that products do not need to ever become waste. The idea presented claims that many materials used in common products today could be replaced with something more durable and long lasting, and with a secondary use in mind at the design stage. This would improve the concept of 'recycling', which makes inferior products from poor quality materials.

Waste prevention is the most sustainable option for achieving the biodegradable waste diversion targets, and further economic drivers promoting prevention, particularly of food and paper/card waste, will be essential to achieve a sustainable economy. The WFD 2008 contains many references to waste prevention, aside from its place at the top of the hierarchy, including promotion of the use of LCA for a product's whole life cycle, instead of separating the end of life; requirement to develop waste prevention programmes to break the link with economic growth; encouraging the use of economic instruments for waste prevention; and extended producer responsibility. More recently in the European Parliament the idea of developing an economy, based on sustainable materials management and resource efficiency has been put at the top of the agenda by Flemish Environment Minister Joke Schauvliege (Eutrio, 2010). She identified waste materials as 'symptoms of maladjusted manufacturing and consumption processes that we must change to ensure there is as little residual waste as possible.' She further went on to say that where waste is unavoidable its hazardous content must be minimised so that it can be returned to the environment without causing harm. Thus although legislation has yet to be passed, at least Europe is starting to talk about waste prevention, and will hopefully move towards regulation, rather than relying on voluntary agreements as appears to be the current method. The Dutch government has embraced the concept, though are yet to pass relevant legislation. But even if passed, this type of legislation is very ambitious, and whether successful implementation at the European wide level might be difficult to achieve.

One of the difficulties in implementing a waste prevention strategy in the UK is the misunderstanding of the terms avoidance, reduction, reuse, recycling and recovery when applied to waste management. Most people appear to consider these synonymous with prevention, however, it only applies to the first three of these. In particular, the strong promotion of recycling over the past ten years has led to the widespread belief that this is the most environmentally beneficial option. A Defra funded study WR1204 on the feasibility of implementing waste prevention strategy identified this as a barrier (Brook Lyndhurst, 2009). This can be illustrated by looking at the London Borough of Barnet, which has an abundance of charity shops, a bring site, and infrequent kerbside collections for unwanted clothes. Separately to this a recycling box is provided for textile waste. Most people consider taking clothes to a charity shop recycling, so if they are not of high enough quality for reuse will put them in the residual waste bin rather than using the kerbside recycling facility. Another

example of the misinterpretation arises in the WR1204 report itself, which considers home-composting a waste prevention measure. While home-composting removes waste from Council responsibility, waste is still produced so it is still a waste treatment with potential environmental impacts. The promotion of this as waste prevention justifies to even the most environmentally concerned consumers of purchasing and disposing of cheap food. Encouraging the prevention of waste under separate legislation as management of resources might be a better way to separate these different concepts in the public eye.

The Circular Economy Law of the People's Republic of China which came into force on 1st of January 2009 (Xue et al., 2010) could provide an example to Europe of ways of successfully implementing such ambitious legislation. The legislation aims to develop an entirely closed loop economic system where economic activities operate with feedback systems, mimicking natural ecosystems. The concept has been successfully implemented in large industrial corporations, for example the Nanning Sugar Co. Ltd The company has formed symbiotic relationships with industry partners so that any by-products form inputs for another product, rather than becoming waste (Yang and Feng, 2008). It is noted though, that the company has control over the other companies which form symbiotic relationships with the main industry. For the same success to be achieved by companies with diverse ownership, good communication and management is identified as the most important factor. The idea of 'material exchanges' was born in the UK, however, was not widely established at the same rates as uptake in other countries. It is operated outside of regulation, often implemented by third sector organisations, although some companies do charge for unwanted goods where companies or individual advertise unwanted materials which another other companies or individuals can browse to find input materials for their process. While success can be achieved by larger corporations, the filtering down into smaller businesses and the general of the circular economy mentality does not appear to have been as successful. (Xue et al., 2010) investigated this and found that the main barriers to successful implementation are lack of public awareness combined with a lack of financial support. Closing the gap between legislation and practical implementation therefore remains a challenge. China has the world's largest population and has seen massive economic growth in recent years. As Europe aims to implement a similar widespread move towards sustainable economy, the barriers identified in China especially relating to communication can be addressed earlier on in the implementation to ensure success.

Therefore developing separate legislation for resource management, rather than trying to re-educate the public about waste prevention, may make it easier to implement at a household level by avoiding the confusion surrounding the definition of waste management practises. In the case of biodegradable wastes in particular, it could for example, increase awareness of the limited recyclability of paper without making keen participants feel that separating waste for recycling had been a waste of time, and the environmental implications of food waste treatment encouraging people to only purchase what they need, cook sensible portions and ultimately save money, while improving the environment. This will be the first step to becoming a genuinely sustainable society.

10. Conclusions and suggestions for future work

The overall aim of this thesis was to compare the environmental impacts of different waste management systems for treating the residual waste stream from households in the UK, with emphasis on the diversion of the biodegradable fraction from landfill.

The first objective, presented in Chapter 3, was to use the WRATE LCA tool to compare the environmental impacts of landfilling residual waste to incineration and MBT using the London Borough of Barnet as a case study. 10 different MBT processes were assessed. Incineration was found to have a good environmental performance in most impact categories, especially GHG emissions and abiotic resource depletion. MBT processes had variable results depending on the amount of recycling and the fate of the biodegradable fraction. MBT processes which largely landfilled CLOs were the worst option for the environment with little or no advantage over landfilling directly; MBT to produce a soil conditioner for application to land was a better performing option in most impact categories, although was worse for eutrophication and freshwater ecotoxicity impacts; MBT to produce SRF gave the best environmental performance of the three outputs options.

The second objective, presented in chapter 4, considered how variation of the mix of fuels used to produce electricity, would impact the perceived environmental benefits of producing energy from waste. The WRATE modelling was repeated with the electricity changed from the 2010 UK mix of fuels, to Norway 2002, which is nearly all renewable hydropower; France 2002 which is mainly nuclear with some renewables, and Lithuania 2002, which is mainly nuclear, with some fossil fuels. It was found that the environmental benefits of incineration were significantly decreased when modelled with the Norwegian fuel mix compared to the UK fuel mix, producing impacts similar to those of landfilling. A small decrease in environmental benefit was also seen when model results with the French and Lithuanian fuel mixes were compared with the UK. For the MBT plants, processes that produced significant amounts of SRF also showed a decrease in environmental benefit, although this was far less significant than the incineration scenario. MBT processes that were net users of energy showed a very slight increase in environmental benefit with all 3 case studies, when compared with the UK case. The results for incineration are concerning as the UK Government is committed to changing to low emitting fuel sources for electricity

production in the near future. If the environmental impacts of incineration are going to be similar to those of landfilling waste within the next 25 years, investment in incineration plants may turn out to be a poor decision for waste management, both environmentally and economically.

The third objective, presented in Chapter 5, began the work into obtaining UK based data related to compost-like outputs (CLOs) from MBT plants, which was lacking due to the fact that this is a relatively new technology to the UK. Samples of CLOs from two different MBT processes currently operating in the UK were analysed for cellulose, hemicellulose, lignin and moisture content, along with a sample from an anaerobic digestion process, which only accepted food waste and grass cuttings, and a composting process which only accepted food and garden waste. The first stage of the analysis was a visual examination to assess the extent of non-biodegradable contamination. The composting sample was the cleanest, followed by the digestate, which was relatively clean except for high levels of corn starch based plastic bags, which had not degraded during the digestion process. The contamination in the 2 MBT output samples was lower in the sample which had a more stringent screening process. The moisture and biological content measurements indicated that the composition of the incoming waste stream was the main factor influencing the output, followed by the length of biological treatment time.

The fourth objective, presented in Chapter 6, was achieved by using the data obtained in the third objective in conjunction with the GasSim model, to produce a long term gas emissions profile from landfills accepting CLOs in significant quantities. This novel approach to assessing the implication for landfill management is advantageous to more common testing methods which determine the total biodegradability of samples, as these tests do not provide an indication of the way these samples will behave in a landfill. Although they quantify the reduction in biodegradability compared to untreated waste, the way they will degrade in the anaerobic environment of a landfill is dependent on the biological structure, not the total biodegradability. The results of this modelling showed that although the total amount of gas emitted from a landfill will be reduced, the timescale over which emissions occur will remain similar to that for untreated waste. The implication of this for landfill management will be loss of revenue due the reduction in gas flow rate, making it impossible to recover for energy use, and increased difficulty in flaring the gas to prevent release to the atmosphere.

Comparison of the total GHG emissions determined by GasSim, with those generated by the WRATE model for MBT processes that largely landfilled the outputs from the biological treatment phase showed good agreement.

The fifth objective, presented in Chapter 7 considered the use of MBT outputs as either a solid recovered fuel (SRF) or a soil conditioner for application to land. The WRATE model assumes that all products will be used for their intended purpose, however, this may not necessarily be the case if customers are not interested. Previous analysis into the potential SRF market, were theoretical approaches based on the number and size of industries that have large energy requirements. In this work a more realistic approach was taken, by interviewing the key players in each of these industries and asking their opinion of the product, as well as a review of any information these companies had published online. The main drivers to using SRF were found to be economic incentives, both the opportunity to receive a gate fee for accepting SRF, as opposed to having to pay for a fuel, and various government incentive schemes. Improved 'green' credentials was also considered a driver to SRF use. The main barriers were concerns over quality and reliability. The results of these interviews fill this important knowledge gap, giving more realistic insight into the potential for SRF to provide a significant route for diverting biodegradable waste from landfill. Calculations based on the data gathered during the both interviews and the literature review indicated that between 7.9 and 8.4 Mt of BMW could potentially be used as SRF, approximately half of the total amount generated in the UK annually. The use of CLOs as a soil conditioner was assessed through a literature review. The potential use of this product is much less likely at the moment due to current Environment Agency restrictions, negative past experiences and concerns over contamination from other parts of the residual waste stream. No drivers were identified at the moment, although preliminary results from trials currently underway in the UK indicate that the product may be safe to use on certain types of food crops. The long term results from these trials, if they continue to be positive, may increase the potential market for this product.

The sixth objective, presented in Chapter 8, was an attempt to assess the GHG emissions associated with the use of CLOs as a soil conditioner. Previous research into the use of CLOs in this context focus on soil quality and leachate, but overlook atmospheric emissions, a significant oversight considering reducing GHG emissions is one of the drivers behind the

biodegradable waste diversion targets in the Landfill Directive. The processes that produce GHG in soils are poorly understood, therefore producing experimental data is extremely important for developing a better understanding of these. Samples from a UK based MBT plant were obtained, along with a sample of compost from a plant accepting food and garden waste only, and an anaerobically digested sewage sludge sample. In order to measure the gas emissions, a flux chamber technique, developed by the Centre for Ecology and Hydrology, which is widely used throughout Europe to assess GHG emissions from soils, was adapted to capture gas emissions from soils which had the above mentioned samples applied. The technique was successfully adapted to this new purpose. Unfortunately subsequent analysis of the gas samples, which had to be performed externally due to time and budget constraints, failed to provide useful data, for comparison with the results of the WRATE analysis. However, it is hoped that the publication of this experiment will stimulate further research into this important issue.

The seventh objective was to investigate the impact on the WRATE modelling results if the composition of the residual waste stream were to change significantly, due to behavioural changes over time. This consideration is important as significant changes in residual waste composition have been seen over the last 25 years, the timescale that many waste treatment plants need to operate in order to be economically feasible. The first case investigated widespread use of in-sink food waste disposal units removing food waste from the residual waste stream. It was found that this would lead to system failure of one MBT process. The benefit of producing energy from waste was reduced, due to the reduction in calorific value of the waste stream, while landfilling impacts were improved, due to the reduced biodegradable content. The second case considered the widespread use of home-composting units, removing both food and garden waste from the residual stream. This led to system failures for all the MBT processes, as expected. The GHG benefits of incineration were reduced, due to the reduced calorific value of the residual waste stream. Acidification and eutrophication impacts were both worse in the home-composting scenario, due to the production of NO_X gases from the composting process, and the increase in the amount of compost applied to land, increasing the potential for eutrophying pollutants to be leached into waterways.

The significance of the limitations identified through objective 7, is important for the application of LCA to waste management systems. This is especially important in the UK, where this type of assessment is likely to be carried out by non-experts of LCA, due to the user friendly interface of WRATE, and regulatory support for the use of LCA in waste management decision-making. Discussion on other options for decision making in waste management, suggested increasing producer responsibility, so the end-of-life of products is considered at their design stage. This could improve the quality of products making them more readily recyclable or easier to dispose of without causing environmental harm. The prevention of biodegradable waste was also considered to be a superior approach, and significant opportunities for preventing biodegradable wastes were identified, particularly better education of the general public on the financial savings from being more careful especially with food and paper waste.

Recommendations for future work

It will be important to improve understanding of the mechanisms that control the production and consumption of N_2O in soils, particularly when CLOs are applied, to ensure that GHG emissions are accounted for accurately. Therefore repeating the experiment in Chapter 8, over a longer period of time and with improved analytical techniques, that have greater sensitivity and can measure N_2O directly is recommended.

Distances between where waste is generated and where it is treated were not taken into consideration in this work, as it was outside the system boundary specified for this assessment. However, if the location of waste treatment facilities shows a dependence, for example landfills are usually located further away from generation areas than MBT or incinerators, the impacts from vehicle emissions might be significant. Assessment of locations would therefore be an important further consideration.

Further work into waste prevention, assessing whether a sustainable closed loop economy would be really be achievable is also recommended, although implementation of this would be expected to be very long term, and therefore waste treatment facilities will still need to be developed in the interim period.

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Appendices

Appendix A: Complete tables of product and reject outputs from MBT processes in Chapter 3

Table 23: MBT product outputs

Waste Fraction	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	$2.0E^{+06}$	$6.7E^{+06}$	$6.1E^{+06}$	$6.9E^{+06}$	$8.2E^{+06}$	$9.8E^{+06}$	$7.8E^{+06}$	$7.9E^{+06}$	$1.1E^{+07}$	$1.1E^{+07}$
Paper and card	$0.0E^{+00}$	$0.0E^{+00}$	$1.6E^{+06}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$1.4E^{+06}$	$0.0E^{+00}$
Plastic film	$0.0E^{+00}$	$7.3E^{+05}$	$1.2E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$4.9E^{+05}$	$0.0E^{+00}$
Dense plastic	$0.0E^{+00}$	$9.6E^{+05}$	$1.7E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$6.4E^{+05}$	$0.0E^{+00}$
Textiles	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Absorbent hygiene products	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Wood	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$5.7E^{+05}$	$0.0E^{+00}$
Combustibles	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Non-combustibles	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$7.6E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$5.8E^{+04}$
Glass	$0.0E^{+00}$	$2.6E^{+05}$	$1.4E^{+05}$	$3.4E^{+05}$	$0.0E^{+00}$	$3.7E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$2.3E^{+05}$	$5.9E^{+04}$
Organic	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Ferrous metal	$6.1E^{+04}$	$5.4E^{+04}$	$1.3E^{+05}$	$5.2E^{+04}$	$4.5E^{+04}$	$5.9E^{+04}$	$4.9E^{+04}$	$1.2E^{+04}$	$5.2E^{+04}$	$5.2E^{+04}$
Non-ferrous metal	$7.3E^{+04}$	$4.8E^{+04}$	$9.6E^{+04}$	$5.3E^{+04}$	$4.3E^{+04}$	$8.1E^{+04}$	$4.5E^{+04}$	$0.0E^{+00}$	$5.3E^{+04}$	$5.3E^{+04}$
Fines	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
WEEE	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Specific hazardous household	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$1.2E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Processed Materials										
Compost	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$4.4E^{+06}$	$0.0E^{+00}$	$2.7E^{+06}$	$0.0E^{+00}$
RDF	$1.9E^{+06}$	$0.0E^{+00}$	$0.0E^{+00}$	$6.4E^{+06}$	$8.1E^{+06}$	$8.4E^{+06}$	$3.3E^{+06}$	$7.9E^{+06}$	$5.1E^{+06}$	$1.1E^{+06}$
Stabilite	$0.0E^{+00}$	$4.6E^{+06}$	$3.8E^{+06}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$9.9E^{+06}$

Table 24: MBT reject outputs

Waste Fraction	Haase	Arrowbio	Global Renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	$7.5E^{+06}$	$6.5E^{+06}$	$5.5E^{+06}$	$3.9E^{+06}$	$2.6E^{+06}$	$6.2E^{+05}$	$2.0E^{+06}$	$5.1E^{+06}$	$0.0E^{+00}$	$2.9E^{+05}$

Paper and card	$0.0E^{+00}$	$2.1E^{+05}$	$3.6E^{+05}$	$3.0E^{+05}$	$6.0E^{+04}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Plastic film	$0.0E^{+00}$	$2.4E^{+05}$	$5.8E^{+05}$	$1.4E^{+05}$	$2.8E^{+04}$	$0.0E^{+00}$	$4.4E^{+03}$	$4.9E^{+02}$	$0.0E^{+00}$	$7.0E^{+04}$
Dense plastic	$0.0E^{+00}$	$3.2E^{+05}$	$4.8E^{+05}$	$1.5E^{+05}$	$4.3E^{+04}$	$0.0E^{+00}$	$5.1E^{+03}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Textiles	$0.0E^{+00}$	$5.6E^{+05}$	$1.6E^{+06}$	$1.1E^{+04}$	$1.5E^{+04}$	$0.0E^{+00}$	$3.4E^{+04}$	$0.0E^{+00}$	$0.0E^{+00}$	$6.2E^{+04}$
Absorbent hygiene products	$0.0E^{+00}$	$7.1E^{+05}$	$1.3E^{+05}$	$3.8E^{+05}$	$1.4E^{+04}$	$0.0E^{+00}$	$0.0E^{+00}$	$7.1E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$
Wood	$0.0E^{+00}$	$1.1E^{+06}$	$6.5E^{+05}$	$9.8E^{+05}$	$3.1E^{+04}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$7.5E^{+04}$
Combustibles	$0.0E^{+00}$	$6.7E^{+05}$	$5.3E^{+05}$	$6.7E^{+03}$	$2.1E^{+04}$	$0.0E^{+00}$	$4.4E^{+04}$	$0.0E^{+00}$	$0.0E^{+00}$	$9.0E^{+03}$
Non-combustibles	$0.0E^{+00}$	$8.5E^{+05}$	$8.9E^{+05}$	$6.9E^{+05}$	$8.1E^{+05}$	$0.0E^{+00}$	$7.8E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$1.1E^{+04}$
Glass	$0.0E^{+00}$	$1.2E^{+05}$	$1.1E^{+04}$	$7.5E^{+02}$	$3.7E^{+05}$	$0.0E^{+00}$	$3.4E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Organic	$0.0E^{+00}$	$4.7E^{+05}$	$2.3E^{+05}$	$5.0E^{+05}$	$4.9E^{+05}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Ferrous metal	$0.0E^{+00}$	$7.3E^{+03}$	$2.5E^{+04}$	$1.7E^{+03}$	$1.1E^{+04}$	$0.0E^{+00}$	$7.6E^{+03}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Non-ferrous metal	$0.0E^{+00}$	$1.3E^{+04}$	$2.3E^{+04}$	$7.4E^{+03}$	$1.0E^{+04}$	$0.0E^{+00}$	$1.0E^{+04}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Fines	$0.0E^{+00}$	$4.7E^{+05}$	$1.7E^{-01}$	$4.7E^{+03}$	$3.2E^{+05}$	$0.0E^{+00}$	$7.4E^{+03}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
WEEE	$0.0E^{+00}$	$6.2E^{+05}$	$5.8E^{-01}$	$5.9E^{+05}$	$2.9E^{+05}$	$6.2E^{+05}$	$6.2E^{+05}$	$2.1E^{+05}$	$0.0E^{+00}$	$6.2E^{+04}$
Specific hazardous household	$0.0E^{+00}$	$1.5E^{+05}$	$6.7E^{+02}$	$1.4E^{+05}$	$6.9E^{+04}$	$0.0E^{+00}$	$1.5E^{+05}$	$6.0E^{+04}$	$0.0E^{+00}$	$0.0E^{+00}$
Processed Materials										
Compost	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
RDF	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$
Stabilite	$7.5E^{+06}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$0.0E^{+00}$	$4.1E^{+06}$	$0.0E^{+00}$	$0.0E^{+00}$

Appendix B: WRATE modelling emissions by pollutant

Table 25: GHG emissions by substance (kg CO_2 equivalents)

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-1.6E+07	-4.1E+07	-3.7E+07	-4.8E+07	-4.0E+07	-4.0E+07	-4.7E+07	-5.3E+07	-3.4E+07	-3.2E+07	-5.8E+07	-2.7E+07
Carbon dioxide (CO_2)	4.9E+04	4.9E+04	4.9E+04	5.3E+04	6.0E+04	4.9E+04	4.9E+04	4.9E+04	4.9E+04	4.8E+04	6.0E+04	4.9E+04
Carbon dioxide, fossil	-3.8E+07	-3.4E+07	-4.7E+07	-6.3E+07	-5.1E+07	-3.4E+07	-3.2E+07	-3.5E+07	-2.3E+07	-2.7E+07	-4.8E+07	-4.0E+07
Carbon Monoxide (CO)	5.3E+04	-1.7E+03	4.1E+04	5.3E+04	3.4E+04	6.5E+03	1.2E+04	5.1E+02	-3.1E+02	2.0E+04	5.4E+03	3.7E+04
Carbon monoxide, biogenic	-3.0E+05	-3.0E+05	-4.9E+05	-4.3E+05	-5.5E+05	-4.4E+05	-4.1E+05	-5.1E+05	-4.2E+05	-3.0E+05	-4.4E+05	-4.4E+05
Carbon monoxide, fossil	-1.4E+05	-1.6E+05	-1.9E+05	-2.4E+05	-2.4E+05	-1.9E+05	-1.8E+05	-2.0E+05	-1.9E+05	-1.5E+05	-2.2E+05	-1.8E+05
Carbon tetrachloride [Tetrachloromethane]	2.4E+02	5.4E+01	5.7E+02	2.1E+02	1.5E+02	9.6E+01	3.0E+01	1.3E+01	2.3E+01	-5.3E+02	8.1E+00	-9.1E+00
Chlorinated Matter (unspecified, as Cl)	-8.3E-05	-2.7E-06	-4.0E-05	-9.9E-05	-8.0E-05	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-4.9E-04	-9.8E-05	-2.3E-04
Dichloromethane	1.2E+00	-7.5E-01	3.6E-01	8.1E-01	4.0E-01	8.9E-02	-4.1E-01	-5.3E-01	-4.6E-01	-1.2E-01	-5.6E-01	8.0E-01
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-3.3E+01	-3.3E+01	-1.9E+01	-3.4E+01	-4.4E+01	-3.5E+01	-3.4E+01	-3.6E+01	-4.2E+01	-3.1E+01	-3.5E+01	-3.7E+01
Ethane, 1,1,1-trichloro-, HCFC-140	1.6E+03	2.6E+01	4.3E+02	1.2E+03	5.7E+02	8.2E+02	4.5E+02	7.3E+02	7.6E+02	4.8E+02	1.5E+02	1.1E+03
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2.6E+04	4.4E+02	6.3E+03	1.9E+04	1.0E+04	1.2E+04	7.1E+03	1.1E+04	1.2E+04	7.8E+03	2.6E+03	1.7E+04
Ethane, 1,1-difluoro-, HFC-152a	-7.5E-01	-7.9E-01	-8.2E-01	-8.0E-01	-9.5E-01	-8.5E-01	-8.5E-01	-8.8E-01	-8.1E-01	-9.4E-01	-9.3E-01	-8.4E-01
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	3.0E+04	-1.7E+03	5.2E+03	2.1E+04	9.5E+03	1.3E+04	6.2E+03	1.0E+04	1.2E+04	7.5E+03	2.9E+02	1.9E+04
Ethane, 1-chloro-1,1-difluoro-, HCFC-142	2.1E+03	3.5E+01	5.9E+02	1.6E+03	7.8E+02	1.1E+03	6.2E+02	9.8E+02	1.0E+03	6.5E+02	2.0E+02	1.5E+03
Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	2.2E+01	3.7E-01	5.4E+00	1.6E+01	8.6E+00	1.1E+01	6.0E+00	9.0E+00	9.8E+00	6.7E+00	2.2E+00	1.4E+01
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	8.3E+01	1.3E+00	2.3E+01	6.3E+01	3.0E+01	4.3E+01	2.4E+01	3.8E+01	4.0E+01	2.5E+01	7.8E+00	5.8E+01
Hydrocarbons (unspecified)	-1.0E+02	1.7E+03	-9.9E+01	-1.3E+02	-1.5E+02	-1.2E+02	-1.1E+02	-1.2E+02	-2.0E+02	-1.0E+02	-1.9E+02	-1.1E+02
Methane, (unspecified)	2.9E+07	5.4E+05	2.4E+07	2.7E+07	2.1E+07	1.1E+07	3.7E+06	1.5E+06	1.2E+06	9.8E+06	3.7E+06	2.4E+07
Methane, biogenic	8.4E+03	6.5E+03	3.3E+04	2.5E+04	3.9E+04	7.1E+04	4.5E+04	4.6E+04	9.2E+03	4.1E+04	4.5E+04	4.2E+04
Methane, bromochlorodifluoro-, Halon	7.0E+01	-3.3E+02	4.1E+01	1.5E+01	1.8E+03	7.8E+01	8.5E+01	1.0E+02	3.6E+02	4.0E+01	9.8E+01	5.0E+01

1211												
Methane, bromotrifluoro-, Halon 1301	-5.1E+02	-4.9E+02	-8.9E+02	-8.3E+02	-1.1E+03	-8.5E+02	-7.9E+02	-9.8E+02	-8.9E+02	-5.5E+02	-9.1E+02	-7.8E+02
Methane, chlorodifluoro-, HCFC-22	3.0E+03	-9.4E+02	7.9E+02	2.1E+03	6.8E+03	1.6E+03	9.5E+02	1.5E+03	2.4E+03	8.3E+02	4.3E+02	2.0E+03
Methane, chlorotrifluoro-, CFC-13	1.1E+04	1.9E+02	2.8E+03	8.4E+03	4.5E+03	5.5E+03	3.1E+03	4.7E+03	5.1E+03	3.5E+03	1.1E+03	7.5E+03
Methane, dichlorodifluoro-, CFC-12	6.7E+04	1.1E+03	1.9E+04	5.1E+04	2.5E+04	3.5E+04	1.9E+04	3.1E+04	3.3E+04	2.0E+04	6.4E+03	4.7E+04
Methane, fossil	-2.9E+06	-4.5E+06	-6.5E+06	-5.5E+06	-1.6E+06	-1.0E+07	-1.3E+07	-1.3E+07	-6.6E+06	-1.0E+07	-8.1E+06	-4.4E+06
Methane, tetrafluoro-, FC-14	-3.8E+06	-3.8E+06	-6.3E+06	-5.5E+06	-7.1E+06	-5.6E+06	-5.3E+06	-6.6E+06	-5.4E+06	-3.8E+06	-5.6E+06	-5.6E+06
Methane, trichlorofluoro-, CFC-11	1.5E+03	2.6E+01	3.7E+02	1.1E+03	5.9E+02	7.2E+02	4.1E+02	6.2E+02	6.7E+02	4.6E+02	1.5E+02	9.9E+02
Methane, trifluoro-, HFC-23	-1.2E+00	-4.5E-01	-8.1E-01	-1.4E+00	-1.3E+00	-1.5E+00	-1.4E+00	-1.6E+00	-1.4E+00	-5.1E+00	-1.4E+00	-2.6E+00
Methyl bromide [Bromomethane]	3.1E-08	3.1E-08	4.9E-08	4.3E-08	5.6E-08	4.4E-08	4.2E-08	5.1E-08	4.2E-08	3.0E-08	4.5E-08	4.4E-08
Methyl chloride [Chloromethane]	3.0E+00	1.7E-01	1.8E+00	2.5E+00	1.9E+00	1.4E+00	6.6E-01	4.9E-01	5.8E-01	1.1E+00	4.4E-01	2.5E+00
Nitrous oxide	-2.1E+05	1.8E+06	-1.2E+05	-1.8E+05	-1.1E+05	2.9E+05	1.2E+05	1.4E+05	1.2E+05	-8.6E+05	8.3E+04	-2.5E+05
Sulphur hexafluoride	-5.0E+04	-5.1E+04	-5.4E+04	-5.3E+04	-6.4E+04	-5.3E+04	-5.3E+04	-5.5E+04	-5.3E+04	-5.5E+04	-6.1E+04	-5.4E+04

Table 26: Abiotic resource depletion by substance (kg antimony equivalents)

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-3.6E+05	-5.5E+05	-6.5E+05	-6.4E+05	-1.7E+05	-8.4E+05	-9.7E+05	-1.0E+06	-5.6E+05	-8.0E+05	-7.3E+05	-4.8E+05
Aluminium, 24% in bauxite, 11% in crude ore, in ground	-2.4E-02	-2.4E-02	-4.0E-02	-3.4E-02	-4.4E-02	-3.5E-02	-3.3E-02	-4.1E-02	-3.4E-02	-2.4E-02	-3.6E-02	-3.5E-02
Anhydrite, in ground	-1.6E-03	-1.6E-03	-1.6E-03	-3.5E-03	-1.9E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-2.9E-03	-1.6E-03
Barite, 15% in crude ore, in ground	-4.6E-01	-8.2E-01	-8.2E-01	-8.7E-01	-2.1E-02	-7.0E-01	-6.3E-01	-7.7E-01	-5.5E-01	-4.9E-01	-7.3E-01	-6.9E-01
Borax, in ground	1.6E-03	1.7E-01	1.3E-01	5.3E-03	1.8E-03	1.6E-03	1.6E-03	1.6E-03	1.5E-03	1.6E-03	1.6E-02	1.6E-03
Calcite, in ground	-2.5E-04	1.8E-04	-4.0E-04	-4.0E-04	-4.8E-04	-3.4E-04	-3.2E-04	-3.5E-04	-3.4E-04	-3.5E-04	-3.3E-04	-3.2E-04
Cerium, in ground	7.2E-18	7.1E-18	1.2E-17	1.0E-17	1.4E-17	1.1E-17	1.0E-17	1.2E-17	1.0E-17	7.5E-18	1.1E-17	1.1E-17
Chromium, 25.5 in chromite, 11.6% in crude ore, in ground	1.0E-01	9.5E-01	3.5E-01	5.9E-01	7.5E-01	3.7E-01	5.1E-01	5.8E-01	3.5E-01	-3.8E-01	3.3E-01	-8.6E-02
Chrysotile, in ground	-3.4E-09	-1.8E-09	-7.0E-09	-5.9E-09	-7.2E-09	-6.1E-09	-5.6E-09	-7.4E-09	-5.7E-09	-1.3E-08	-5.1E-09	-9.3E-09
Cinnabar, in ground	-1.4E-01	-7.4E-02	-8.9E-02	-2.3E-01	-2.8E-01	-2.4E-01	-2.2E-01	-3.0E-01	-2.3E-01	-5.2E-01	-2.1E-01	-3.7E-01
Coal (in ground)	-9.5E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03

Coal, brown, in ground	-3.3E+04	-3.4E+04	-4.3E+04	-4.0E+04	-4.9E+04	-4.2E+04	-4.1E+04	-4.6E+04	-4.0E+04	-3.8E+04	-4.4E+04	-4.2E+04
Coal, hard, unspecified, in ground	-1.7E+05	-2.5E+05	-4.0E+05	-2.7E+05	-2.4E+05	-6.2E+05	-7.6E+05	-8.0E+05	-4.1E+05	-6.0E+05	-4.4E+05	-2.6E+05
Cobalt, in ground	1.0E-07	-2.4E-08	-2.6E-07	-2.9E-07	-5.2E-07	-3.0E-07	-2.2E-07	-5.6E-07	-5.3E-07	2.7E-08	-5.2E-07	-2.1E-07
Colemanite, in ground	5.6E-02	5.7E-02	5.3E-02	5.4E-02	5.2E-02	5.4E-02	5.4E-02	5.2E-02	5.8E-02	5.5E-02	5.4E-02	5.3E-02
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	-1.5E+00	-1.5E+00	-2.2E+00	-2.0E+00	-2.5E+00	-2.1E+00	-2.0E+00	-2.4E+00	-2.0E+00	-1.8E+00	-2.1E+00	-2.1E+00
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	-8.2E+00	-8.2E+00	-1.2E+01	-1.1E+01	-1.4E+01	-1.1E+01	-1.1E+01	-1.3E+01	-1.1E+01	-9.9E+00	-1.2E+01	-1.2E+01
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	-2.2E+00	-2.2E+00	-3.3E+00	-3.0E+00	-3.7E+00	-3.0E+00	-2.9E+00	-3.5E+00	-2.9E+00	-2.6E+00	-3.1E+00	-3.2E+00
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	-1.1E+01	-1.1E+01	-1.6E+01	-1.5E+01	-1.7E+01	-1.5E+01	-1.4E+01	-1.7E+01	-1.4E+01	-1.3E+01	-1.5E+01	-1.6E+01
Dolomite, in ground	7.7E-08	9.5E-08	8.1E-08	8.9E-08	1.4E-07	8.0E-08	8.3E-08	9.4E-08	8.1E-08	7.8E-08	1.1E-07	7.8E-08
Fluorine, 4.5% in apatite, 1% in crude ore, in ground	1.4E-04	4.5E-04	1.2E-04	1.7E-04	1.5E-04	1.2E-04	1.2E-04	1.2E-04	1.3E-04	-2.6E-02	1.6E-04	-8.4E-03
Fluorine, 4.5% in apatite, 3% in crude ore, in ground	-4.5E-03	-4.4E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.1E-03	-4.5E-03	-1.6E-02	-4.5E-03	-8.2E-03
Fluorspar, 92%, in ground	-3.9E-03	-1.7E-03	-6.3E-03	-5.2E-03	-6.8E-03	-5.7E-03	-5.3E-03	-6.6E-03	-5.4E-03	-1.8E-01	-5.5E-03	-6.4E-02
Gas, mine, off-gas, process, coal mining	-2.6E+03	-4.1E+03	-7.4E+03	-4.2E+03	-3.5E+03	-1.3E+04	-1.6E+04	-1.7E+04	-8.1E+03	-1.3E+04	-8.5E+03	-4.5E+03
Gas, natural, in ground	-5.6E+04	-1.6E+05	-6.8E+04	-1.4E+05	2.7E+05	-3.9E+04	-3.4E+04	-2.5E+04	2.4E+04	-4.3E+04	-6.5E+04	-5.2E+04
Gypsum, in ground	3.1E-03	3.0E-03	4.7E-03	2.1E-02	5.3E-03	4.2E-03	4.0E-03	4.8E-03	4.0E-03	3.1E-03	4.7E-03	4.2E-03
Iron, 46% in ore, 25% in crude ore, in ground	-2.3E-01	-2.9E-01	-3.5E-01	-3.3E-01	-4.7E-01	-3.3E-01	-3.1E-01	-3.5E-01	-3.2E-01	-2.5E-01	-3.3E-01	-3.3E-01
Kaolinite, 24% in crude ore, in ground	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.5E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.4E-03	-2.0E-03
Kieserite, 25% in crude ore, in ground	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01
Lanthanum, in crude ore, in ground	4.7E-18	4.7E-18	7.6E-18	6.6E-18	8.6E-18	6.8E-18	6.4E-18	7.9E-18	6.5E-18	4.3E-18	6.8E-18	6.7E-18
Lead (Pb, ore)	-4.1E+01	-4.2E+01	-4.5E+01	-4.9E+01	-5.8E+01	-4.7E+01	-4.6E+01	-5.0E+01	-6.3E+01	-4.1E+01	-6.2E+01	-4.7E+01

Magnesite, 60% in crude ore, in ground	-3.2E-07	3.8E-07	-3.3E-07	1.4E-07	1.3E-06	-3.1E-07	-1.5E-07	2.3E-07	-2.8E-07	-3.3E-07	1.6E-07	-2.7E-07
Magnesium, 0.13% in water	-5.9E-09	-5.9E-09	-6.0E-09	-5.9E-09	-6.5E-09	-6.1E-09	-6.2E-09	-6.2E-09	-6.0E-09	-6.2E-09	-7.1E-09	-5.9E-09
Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	1.2E-02	2.7E-02	2.0E-02	2.8E-02	2.8E-02	2.0E-02	2.2E-02	3.1E-02	1.6E-02	2.8E-02	2.6E-02	2.2E-02
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	-3.3E+00	-3.3E+00	-4.9E+00	-4.5E+00	-5.2E+00	-4.6E+00	-4.3E+00	-5.2E+00	-4.4E+00	-4.0E+00	-4.6E+00	-4.7E+00
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	-4.7E-01	-4.7E-01	-7.0E-01	-6.3E-01	-7.9E-01	-6.5E-01	-6.2E-01	-7.4E-01	-6.2E-01	-5.6E-01	-6.6E-01	-6.8E-01
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	9.8E+00	2.2E+01	1.6E+01	2.2E+01	2.3E+01	1.6E+01	1.8E+01	2.5E+01	1.3E+01	2.3E+01	2.1E+01	1.8E+01
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	-1.7E+00	-1.7E+00	-2.6E+00	-2.3E+00	-2.9E+00	-2.4E+00	-2.3E+00	-2.7E+00	-2.3E+00	-2.1E+00	-2.4E+00	-2.5E+00
Molybdenum, 0.11% in sulfide, Mo 0.41% and Cu 0.36% in crude ore, in ground	2.0E+01	4.4E+01	3.3E+01	4.5E+01	4.6E+01	3.3E+01	3.6E+01	5.1E+01	2.6E+01	4.6E+01	4.3E+01	3.5E+01
Neodymium, in ground	1.1E-26	1.1E-26	1.8E-26	1.6E-26	2.1E-26	1.7E-26	1.6E-26	1.9E-26	1.6E-26	1.2E-26	1.7E-26	1.7E-26
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	-2.0E-03	4.5E-03	-2.3E-03	-2.4E-03	-2.4E-03	-2.1E-03	-2.0E-03	-2.1E-03	-1.9E-03	-1.5E-02	-2.1E-03	-6.3E-03
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	1.5E-01	6.0E-01	3.3E-01	5.0E-01	6.4E-01	3.4E-01	4.0E-01	5.5E-01	2.8E-01	2.0E-01	4.2E-01	2.2E-01
Oil, crude, in ground	-8.8E+04	-8.9E+04	-1.2E+05	-1.8E+05	-1.4E+05	-1.1E+05	-1.1E+05	-1.2E+05	-1.2E+05	-9.2E+04	-1.6E+05	-1.1E+05
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-8.4E-04	-8.0E-04	-1.3E-03	-1.3E-03	-1.6E-03	-1.3E-03	-1.3E-03	-1.5E-03	-1.4E-03	-1.5E-03	-1.4E-03	-1.4E-03
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-2.0E-03	-1.9E-03	-3.1E-03	-3.1E-03	-3.8E-03	-3.2E-03	-3.0E-03	-3.7E-03	-3.4E-03	-3.7E-03	-3.4E-03	-3.4E-03

Phosphorus, 18% in apatite, 12% in crude ore, in ground	-5.1E-01	-5.0E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-4.7E-01	-5.1E-01	-1.8E+00	-5.1E-01	-9.4E-01
Phosphorus, 18% in apatite, 4% in crude ore, in ground	1.6E-02	5.1E-02	1.3E-02	1.9E-02	1.7E-02	1.4E-02	1.4E-02	1.3E-02	1.4E-02	-2.9E+00	1.8E-02	-9.6E-01
Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-3.7E-04	-3.9E-04	-4.3E-04	-4.2E-04	-5.0E-04	-4.3E-04	-4.3E-04	-4.5E-04	-4.3E-04	-4.2E-04	-4.9E-04	-4.2E-04
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-1.3E-03	-1.4E-03	-1.5E-03	-1.5E-03	-1.8E-03	-1.6E-03	-1.5E-03	-1.6E-03	-1.5E-03	-1.5E-03	-1.7E-03	-1.5E-03
Pyrite, in ground	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.3E-05	9.4E-05	9.3E-05	9.4E-05
Raw Materials (unspecified)	2.8E-17	3.6E-17	2.0E-17	5.0E-17	2.2E-17	1.9E-17	2.0E-17	1.5E-17	2.2E-17	2.1E-17	3.7E-17	2.8E-17
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-2.2E-03	-2.4E-03	-3.4E-03	-3.2E-03	-4.0E-03	-3.3E-03	-3.2E-03	-3.7E-03	-3.4E-03	-2.6E-03	-3.6E-03	-3.1E-03
Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-6.9E-03	-7.6E-03	-1.1E-02	-1.0E-02	-1.3E-02	-1.1E-02	-9.9E-03	-1.2E-02	-1.1E-02	-8.1E-03	-1.1E-02	-9.7E-03
Rhenium, in crude ore, in ground	-7.1E-05	-7.6E-05	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-8.7E-05	-1.2E-04	-9.9E-05
Silver, 0.01% in crude ore, in ground	-1.9E-01	-2.6E-02	-1.0E-01	-2.2E-01	-1.9E-01	-2.4E-01	-2.3E-01	-2.6E-01	-2.4E-01	-1.0E+00	-2.2E-01	-4.9E-01
Sodium chloride, in ground	-3.4E-03	-1.1E-03	-3.4E-03	-5.7E-03	-6.8E-03	-6.0E-03	-5.5E-03	-7.2E-03	-5.6E-03	-2.2E-02	-5.1E-03	-1.2E-02
sodium sulphate, various forms, in ground	-9.3E-03	6.3E-02	-1.1E-02	3.2E-04	-1.0E-03	-1.0E-02	-9.9E-03	-1.0E-02	-9.4E-03	-5.9E+00	-2.9E-03	-2.0E+00
Stibnite, in ground	-6.2E-05	-6.3E-05	-8.2E-05	-7.3E-05	-9.1E-05	-7.9E-05	-7.8E-05	-8.7E-05	-8.5E-05	-6.9E-05	-9.0E-05	-7.8E-05
Sulfur, in ground	-2.2E-01	-2.2E-01	-2.2E-01	-3.1E-01	-2.5E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.9E-01	-2.2E-01
sylvite, 25 % in sylvinite, in ground	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04
Talc, in ground	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.3E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.2E-04	-1.0E-04
Tin, 79% in cassiterite, 0.1% in crude ore, in ground	-9.5E-02	-5.3E-02	-6.6E-02	-1.1E-01	-1.0E-01	-1.2E-01	-1.1E-01	-1.2E-01	-1.2E-01	-3.3E-01	-1.2E-01	-1.7E-01

Ulexite, in ground	-2.3E-03	-2.0E-03	-1.4E-03	-5.3E-04	-9.6E-04	-1.5E-03	-1.9E-03	-7.9E-04	-9.3E-04	-1.4E-03	-2.2E-03	-1.2E-03
Uranium, in ground	-8.8E-01	-8.9E-01	-1.1E+00	-1.0E+00	-1.2E+00	-1.0E+00	-1.0E+00	-1.1E+00	-9.7E-01	-9.1E-01	-1.2E+00	-1.0E+00
Zinc (Zn, ore)	1.6E+02	1.6E+02	2.7E+02	2.3E+02	3.0E+02	2.4E+02	2.2E+02	2.8E+02	2.3E+02	1.6E+02	2.4E+02	2.4E+02
Zirconia, as baddeleyite, in ground	-6.3E-07	-2.9E-08	-3.1E-07	-7.5E-07	-6.1E-07	-8.0E-07	-7.7E-07	-8.9E-07	-8.1E-07	-3.7E-06	-7.5E-07	-1.7E-06

Table 27: Acidification impacts by pollutant (kg SO_2 equivalent)

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-196043	-157240	-264626	-278908	-276145	-281155	-271088	-301358	-238050	-231749	-328168	-242374
Ammonia	329	5067	4089	3782	1434	1144	1337	557	5910	3179	6469	5470
Nitrogen oxides (NO and NO_2 as NO_2)	-29114	16070	-22083	-50526	-44432	1120	23109	22877	-8797	20132	-42268	-26717
Sulfur dioxide	-155066	-172018	-213697	-220993	-220143	-195259	-187916	-214420	-183282	-178514	-210254	-199751
Sulphur oxides (SO_2 and SO_3 as SO_2)	-12192	-6359	-32934	-11171	-13004	-88161	-107619	-110372	-51881	-76546	-82116	-21377

Table 28: Eutrophication impacts by pollutant (kg PO_4 equivalent)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		1.7E+04	2.0E+03	1.3E+04	1.3E+04	2.0E+03	1.5E+03	4.3E+03	-8.9E+02	4.6E+03	1.2E+04	-6.0E+03	6.4E+03
Ammonia	air	7.2E+01	1.1E+03	8.9E+02	8.3E+02	3.1E+02	2.5E+02	2.9E+02	1.2E+02	1.3E+03	7.0E+02	1.4E+03	1.2E+03
Nitrate	air	5.2E-01	5.3E-01	5.0E-01	5.8E-01	6.6E-01	5.5E-01	5.4E-01	5.6E-01	7.9E-01	5.2E-01	7.7E-01	5.5E-01
Nitrogen oxides (NO and NO_2 as NO_2)	air	-7.6E+03	4.2E+03	-5.7E+03	-1.3E+04	-1.2E+04	2.9E+02	6.0E+03	5.9E+03	-2.3E+03	5.2E+03	-1.1E+04	-6.9E+03
Nitrous oxide	air	-1.9E+02	1.6E+03	-1.1E+02	-1.6E+02	-9.9E+01	2.7E+02	1.1E+02	1.2E+02	1.1E+02	-7.8E+02	7.5E+01	-2.3E+02
Phosphorus	air	-5.7E+01	-5.6E+01	-5.4E+01	-5.3E+01	-6.4E+01	-5.5E+01	-5.6E+01	-5.4E+01	-5.4E+01	-5.6E+01	-6.5E+01	-5.4E+01
Ammonia (NH_4^+, NH_3, as N)	water	3.0E+04	8.1E+02	2.6E+04	3.1E+04	2.2E+04	6.8E+03	5.1E+03	1.6E+03	1.7E+03	1.5E+04	3.6E+03	2.1E+04
Ammonium, ion	water	-6.1E+01	-4.3E+01	-7.4E+01	-7.5E+01	-7.0E+01	-7.6E+01	-7.7E+01	-8.1E+01	-7.1E+01	-1.1E+02	-6.9E+01	-8.4E+01
COD, Chemical Oxygen Demand	water	-2.7E+03	-2.8E+03	-3.5E+03	-2.1E+03	-3.7E+03	-3.2E+03	-3.2E+03	-3.6E+03	-3.3E+03	-2.9E+03	-2.5E+03	-3.3E+03
Nitrate	water	8.8E+02	8.5E+02	8.5E+02	8.4E+02	9.3E+02	8.7E+02	8.8E+02	8.8E+02	8.9E+02	8.7E+02	9.4E+02	8.6E+02
Nitrite	water	-3.0E-01	-3.1E-01	-3.6E-01	-3.7E-01	-2.9E-01	-3.5E-01	-3.4E-01	-3.7E-01	-3.3E-01	-5.3E-01	-2.6E-01	-4.3E-01
Nitrogen	water	1.5E+03	1.5E+03	1.4E+03	1.4E+03	1.4E+03	1.5E+03	1.5E+03	1.4E+03	1.3E+04	1.4E+03	8.2E+03	1.4E+03
Nitrogen - as total N	water	8.1E-01	4.5E-01	8.2E-01	7.9E-01	7.7E-01	8.0E-01	8.1E-01	8.0E-01	7.4E-01	8.2E-01	7.5E-01	8.1E-01
Phosphate	water	-3.9E+03	-4.2E+03	-5.9E+03	-5.3E+03	-6.4E+03	-5.6E+03	-5.3E+03	-6.4E+03	-5.4E+03	-6.3E+03	-5.7E+03	-6.2E+03

Phosphorus	water	-8.2E+02	-8.2E+02	-8.2E+02	-8.1E+02	-8.3E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.5E+02	-8.2E+02	-8.3E+02
Phosphorus - as total P	water	-9.7E-07	-9.5E-07	-9.7E-07	-9.7E-07	-9.7E-07	1.3E+03	-9.7E-07	-9.7E-07	-9.6E-07	-9.7E-07	-9.7E-07	-9.7E-07
Nitrogen	soil	2.0E-05	1.3E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05
Phosphorus	soil	-4.6E+01	-4.8E+01	-4.8E+01	-4.3E+01	-4.1E+01	-4.8E+01	-4.9E+01	-4.6E+01	-4.4E+01	-4.3E+01	-5.6E+01	-4.5E+01

Table 29: Human Toxicity impacts by pollutant (kg 1,4-DCB equivalents)

Substances	**Compartment**	**Landfill**	**Incineration**	**Haase**	**Arrowbio**	**Global renewables**	**Ecodeco**	**Entsorga**	**Herhof**	**Bedminster**	**Linde**	**SRS**	**VKW**
Total		-1.2E+08	-1.2E+08	-1.9E+08	-1.7E+08	-2.1E+08	-1.7E+08	-1.6E+08	-2.0E+08	-1.5E+08	-1.2E+08	-1.6E+08	-1.7E+08
Acenaphthene	air	-4.9E+01	-8.5E+01	-6.1E+01	-8.3E+01	-5.5E+01	-3.3E+01	-2.9E+01	-2.4E+01	-2.2E+01	-2.8E+01	-3.1E+01	-4.3E+01
Acrolein	air	-1.3E+00	-1.2E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00
Ammonia	air	2.1E+01	3.2E+02	2.6E+02	2.4E+02	9.0E+01	7.2E+01	8.4E+01	3.5E+01	3.7E+02	2.0E+02	4.0E+02	3.4E+02
Antimony	air	-2.7E+03	2.3E+04	-2.3E+03	-1.8E+03	-2.5E+03	-1.1E+03	-1.6E+03	-2.8E+03	-8.9E+02	-1.1E+03	-9.4E+02	-1.4E+03
Arsenic	air	-8.0E+05	-3.4E+05	-9.8E+05	-1.0E+06	-1.1E+06	-7.9E+05	-7.8E+05	-8.3E+05	-8.6E+05	-8.7E+05	-8.1E+05	-1.0E+06
Barium	air	-2.9E+03	-3.5E+03	-4.1E+03	-3.9E+03	-4.2E+03	-3.7E+03	-3.7E+03	-4.0E+03	-3.3E+03	-3.3E+03	-3.6E+03	-3.6E+03
Benzene	air	-1.7E+05	-2.6E+05	-2.1E+05	-2.1E+05	-2.2E+05	-1.7E+05	-1.6E+05	-1.8E+05	-1.4E+05	-1.3E+05	-1.6E+05	-1.6E+05
Benzene, ethyl-	air	-4.4E+00	-4.6E+00	-6.3E+00	1.2E+02	-7.5E+00	-6.1E+00	-5.8E+00	-6.7E+00	-6.3E+00	-4.7E+00	-6.8E+00	-5.7E+00
Benzene, pentachloro-	air	5.4E-01	5.6E-01	5.8E-01	5.7E-01	6.7E-01	5.7E-01	5.6E-01	5.9E-01	5.7E-01	5.4E-01	6.2E-01	5.7E-01
Beryllium	air	-4.0E+03	-4.2E+03	-4.9E+03	-4.5E+03	-4.5E+03	-5.2E+03	-5.4E+03	-5.6E+03	-4.8E+03	-5.3E+03	-4.5E+03	-4.6E+03
Butadiene [1,3-Butadiene]	air	1.3E+05	1.2E+05	1.3E+05	1.2E+05	1.1E+05	1.3E+05	1.3E+05	1.3E+05	1.0E+05	1.3E+05	1.1E+05	1.2E+05
Cadmium	air	-1.7E+05	-6.6E+04	-2.3E+05	-2.3E+05	-2.7E+05	-2.0E+05	-1.9E+05	-2.2E+05	-2.0E+05	-2.0E+05	-2.1E+05	-2.3E+05
Carbon disulphide	air	1.4E+02	1.8E+02	2.7E+02	2.5E+02	3.2E+02	2.4E+02	2.3E+02	3.1E+02	1.8E+02	1.5E+02	2.3E+02	2.3E+02
Carbon tetrachloride [Tetrachloromethane]	air	3.8E+01	8.6E+00	8.9E+01	3.3E+01	2.4E+01	1.5E+01	4.7E+00	2.1E+00	3.6E+00	-8.4E+01	1.3E+00	-1.4E+00
Chlorinated Matter (unspecified, as Cl)	air	-4.8E-06	-1.6E-07	-2.3E-06	-5.7E-06	-4.6E-06	-6.1E-06	-5.9E-06	-6.7E-06	-6.2E-06	-2.8E-05	-5.7E-06	-1.3E-05
Chloroform [Trichloromethane]	air	2.1E+00	-2.4E-02	1.2E+00	1.7E+00	1.2E+00	8.9E-01	3.3E-01	2.0E-01	2.8E-01	6.3E-01	1.6E-01	1.7E+00
Chromium VI	air	-2.1E+05	4.4E+04	1.1E+06	1.8E+06	2.1E+06	6.4E+05	6.9E+05	1.0E+06	1.7E+06	1.8E+06	1.7E+06	1.6E+06
Cobalt	air	-1.8E+04	3.2E+03	-2.3E+04	-2.3E+04	-2.3E+04	-2.0E+04	-1.9E+04	-2.0E+04	-1.8E+04	-2.1E+04	-1.9E+04	-2.2E+04
Copper	air	-1.7E+05	-1.4E+05	-2.5E+05	-2.3E+05	-2.9E+05	-2.3E+05	-2.1E+05	-2.6E+05	-2.2E+05	-1.7E+05	-2.2E+05	-2.3E+05
Dichloromethane	air	2.7E-01	-1.7E-01	8.2E-02	1.9E-01	9.0E-02	2.0E-02	-9.3E-02	-1.2E-01	-1.1E-01	-2.8E-02	-1.3E-01	1.8E-01

Dioxins and furans- as ITEQ	air	3.2E+01	2.5E+04	2.6E+03	7.2E+01	7.4E+01	8.9E+03	1.1E+04	1.1E+04	4.2E+03	7.5E+03	8.0E+03	1.1E+03
Dioxins and furans- as WHO TEQ	air	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.5E+02	-2.4E+02	-2.4E+02	-2.4E+02
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.4E+05	-2.5E+05	-2.5E+05	-2.5E+05	-3.2E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-3.0E+05	-2.5E+05
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.8E+02	2.9E+00	4.9E+01	1.4E+02	6.5E+01	9.2E+01	5.1E+01	8.2E+01	8.6E+01	5.4E+01	1.7E+01	1.2E+02
Ethane, 1,2-dichloro-	air	-4.3E+01	-4.6E+01	-4.9E+01	-4.6E+01	-5.9E+01	-4.8E+01	-4.8E+01	-4.9E+01	-4.7E+01	-5.0E+01	-5.6E+01	-4.9E+01
Ethylene [Ethene]	air	1.5E+01	3.9E+00	-7.0E+00	-5.7E+00	3.4E+00	-8.4E+00	-7.8E+00	-1.4E+01	-5.2E+00	1.5E+00	1.4E+01	-3.5E+00
Ethylene oxide [1,2-Epoxyethane]	air	-1.6E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04
Formaldehyde [Methanal]	air	-8.9E+01	-1.1E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.0E+02	-1.0E+02	-1.1E+02	-9.9E+01	-9.2E+01	-1.0E+02	-1.1E+02
Hexachlorobenzene	air	8.4E+02	2.3E+03	9.4E+02	1.9E+03	4.5E+03	9.0E+02	1.2E+03	2.0E+03	1.0E+03	7.3E+02	2.0E+03	7.9E+02
Hydrocarbons (unspecified)	air	-5.6E-01	9.2E+00	-5.4E-01	-6.9E-01	-8.3E-01	-6.2E-01	-6.0E-01	-6.4E-01	-1.1E+00	-5.6E-01	-1.0E+00	-6.2E-01
Hydrogen chloride	air	-8.8E+02	2.6E+02	-8.0E+02	-1.2E+03	6.7E+02	-3.7E+02	-2.7E+02	-3.1E+02	-5.0E+02	-3.9E+02	-8.6E+02	-7.6E+02
Hydrogen fluoride	air	-4.3E+06	-5.1E+06	-6.9E+06	-6.3E+06	-7.6E+06	-6.2E+06	-5.9E+06	-7.2E+06	-5.9E+06	-4.5E+06	-6.3E+06	-6.1E+06
Hydrogen sulfide	air	-1.2E+02	-1.4E+02	-1.2E+02	-1.2E+02	-2.5E+01	-1.2E+02	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02
Lead	air	-3.9E+02	-8.5E+02	1.9E+03	3.2E+02	7.6E+02	1.5E+03	1.4E+03	2.8E+03	1.0E+03	-7.3E+02	1.6E+03	6.5E+02
Mercury	air	-6.3E+03	5.6E+03	-4.8E+03	-6.4E+03	-3.3E+03	-2.5E+03	-2.6E+03	-2.4E+03	-2.2E+03	-7.3E+02	-2.5E+03	-4.5E+03
Methyl bromide [Bromomethane]	air	2.2E-06	2.2E-06	3.5E-06	3.0E-06	3.9E-06	3.1E-06	2.9E-06	3.6E-06	3.0E-06	2.1E-06	3.1E-06	3.1E-06
Molybdenum	air	-1.5E+03	-1.8E+03	-2.2E+03	-2.3E+03	-2.0E+03	-1.9E+03	-1.9E+03	-2.1E+03	-1.7E+03	-2.1E+03	-1.6E+03	-2.1E+03
m-Xylene	air	-2.1E-01	-2.1E-01	-2.0E-01	-2.0E-01	-2.4E-01	-2.0E-01	-2.1E-01	-2.0E-01	-2.0E-01	-2.0E-01	-2.4E-01	-2.0E-01
Nickel	air	-7.9E+05	-3.9E+05	-1.0E+06	-9.6E+05	-1.1E+06	-9.2E+05	-8.6E+05	-1.0E+06	-8.4E+05	-7.8E+05	-8.0E+05	-9.5E+05
Nitrogen oxides (NO and NO_2 as NO_2)	air	-7.0E+04	3.9E+04	-5.3E+04	-1.2E+05	-1.1E+05	2.7E+03	5.5E+04	5.5E+04	-2.1E+04	4.8E+04	-1.0E+05	-6.4E+04
o-Xylene	air			1.1E+01		1.1E+01	4.5E+01	2.0E+01	2.0E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01
PAH, polycyclic aromatic hydrocarbons	air	-1.1E+08	-1.1E+08	-1.7E+08	-1.5E+08	-1.9E+08	-1.5E+08	-1.4E+08	-1.8E+08	-1.5E+08	-1.0E+08	-1.5E+08	-1.5E+08
Particulates, < 2.5 um	air	-1.5E+04	-1.6E+04	-2.1E+04	-2.0E+04	-2.3E+04	-1.9E+04	-1.9E+04	-2.1E+04	-1.9E+04	-1.6E+04	-2.0E+04	-1.9E+04
Particulates, > 2.5 um, and < 10um	air	-2.1E+04	-2.3E+04	-3.2E+04	-3.0E+04	-3.8E+04	-2.9E+04	-2.8E+04	-3.3E+04	-2.8E+04	-2.2E+04	-3.0E+04	-2.9E+04
Pentachlorophenol	air	-4.1E-01	1.3E-01	-4.4E-01	-4.3E-01	-5.2E-01	-4.5E-01	-4.5E-01	-4.6E-01	-4.4E-01	-4.8E-01	-5.1E-01	-4.5E-01
Phenol	air	8.4E-01	1.2E+00	1.1E+00	8.3E-01	1.2E+00	8.5E-01	8.6E-01	8.2E-01	8.6E-01	7.7E-01	1.2E+00	8.1E-01
Propylene oxide	air	4.3E+02	4.3E+02	4.0E+02	4.1E+02	5.1E+02	7.4E+02	7.8E+02	3.9E+02	4.9E+02	3.9E+02	3.9E+02	3.9E+02
Selenium	air	-1.1E+05	-1.3E+05	-1.4E+05	-1.5E+05	-1.5E+05	-1.2E+05	-1.1E+05	-1.2E+05	-1.1E+05	-1.0E+05	-1.2E+05	-1.3E+05

Sodium dichromate	air	-6.2E+03	-1.4E+04	-2.4E+05	-1.6E+05	-2.2E+05	-1.7E+05	-1.4E+05	-2.6E+05	-1.5E+05	-1.2E+04	-9.7E+04	-1.7E+05
Styrene	air	-1.0E-03	-8.8E-04	1.7E+00	1.6E+00	1.6E+00	5.3E+00	1.8E+00	1.9E+00	2.4E+00	2.5E+00	2.6E+00	2.3E+00
Sulfur dioxide	air	-1.2E+04	-1.4E+04	-1.7E+04	-1.8E+04	-1.8E+04	-1.6E+04	-1.5E+04	-1.7E+04	-1.5E+04	-1.4E+04	-1.7E+04	-1.6E+04
Sulphur oxides (SO_2 and SO_3 as SO_2)	air	-9.8E+02	-5.1E+02	-2.6E+03	-8.9E+02	-1.0E+03	-7.1E+03	-8.6E+03	-8.8E+03	-4.2E+03	-6.1E+03	-6.6E+03	-1.7E+03
Tetrachloroethylene	air	1.0E+00	-8.8E-02	5.5E-01	8.1E-01	5.7E-01	3.9E-01	1.1E-01	3.7E-02	7.5E-02	2.7E-01	2.2E-02	8.1E-01
Thallium	air	-6.1E+03	-6.3E+03	1.3E+05	1.3E+05	1.3E+05	6.2E+04	6.1E+04	6.1E+04	1.8E+05	1.8E+05	1.8E+05	1.9E+05
Tin	air	-6.3E-01	1.0E+01	-9.3E-01	-8.2E-01	-1.0E+00	-8.7E-01	-8.1E-01	-9.1E-01	-8.4E-01	-7.8E-01	-8.7E-01	-9.2E-01
Toluene	air	-8.3E+00	-2.2E+01	6.4E+01	3.8E+01	3.8E+01	2.0E+02	1.5E+02	1.6E+02	1.1E+02	1.5E+02	1.5E+02	7.5E+01
Trichloroethylene	air	8.7E+01	1.0E+00	5.0E+01	7.1E+01	5.2E+01	3.8E+01	1.6E+01	1.1E+01	1.4E+01	2.9E+01	9.5E+00	7.0E+01
Vanadium	air	-1.7E+05	-1.6E+05	-2.1E+05	-2.1E+05	-2.1E+05	-2.0E+05	-2.0E+05	-2.2E+05	-1.9E+05	-2.5E+05	-1.8E+05	-2.2E+05
Vinyl chloride	air	-5.6E+01	-6.9E+01	-9.9E+01	-8.4E+01	-1.1E+02	-9.1E+01	-8.9E+01	-1.1E+02	-9.0E+01	-6.7E+01	-9.7E+01	-8.7E+01
Zinc	air	2.6E+04	2.6E+04	4.3E+04	3.8E+04	4.9E+04	3.9E+04	3.6E+04	4.5E+04	3.7E+04	2.6E+04	3.9E+04	3.9E+04
Acenaphthene	water	-1.7E+02	-1.8E+02	-3.0E+02	-2.8E+02	-3.6E+02	-2.9E+02	-2.7E+02	-3.3E+02	-3.0E+02	-1.8E+02	-3.1E+02	-2.6E+02
Acenaphthylene	water	1.7E-01	-7.8E+00	-6.4E+00	-1.1E+01	-2.2E+01	-9.8E+00	-7.7E+00	-1.3E+01	-2.8E+01	-1.0E+00	-2.5E+01	-7.8E+00
Antimony	water	-1.1E+05	-3.8E+03	-1.2E+05	-3.0E+05	-1.5E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.3E+05	-1.7E+05	-1.2E+05
Arsenic	water	4.6E+04	1.7E+03	3.5E+04	4.4E+04	3.7E+04	1.4E+04	1.7E+04	3.7E+03	1.2E+04	1.8E+04	1.8E+04	2.1E+04
Arsenic, ion	water	-1.2E+05	-1.2E+05	-1.9E+05	-1.7E+05	-2.1E+05	-1.7E+05	-1.6E+05	-2.0E+05	-1.6E+05	-1.3E+05	-1.7E+05	-1.7E+05
Barite	water	-4.1E+05	-1.1E+06	-6.2E+05	-9.2E+05	5.3E+05	-2.5E+05	-1.7E+05	-1.2E+05	4.3E+04	-1.5E+05	-2.0E+05	-3.7E+05
Barium	water	-1.9E+05	8.9E+04	-2.8E+05	-2.6E+05	-3.2E+05	-2.7E+05	-2.6E+05	-3.0E+05	-2.6E+05	-2.1E+05	-1.1E+05	-2.6E+05
Benzene	water	-4.4E+04	-4.4E+04	-5.4E+04	-5.2E+04	-6.6E+04	-5.3E+04	-5.1E+04	-5.6E+04	-5.4E+04	-4.6E+04	-6.1E+04	-5.1E+04
Benzene, chloro-	water	-2.6E-01	-2.1E-02	-1.3E-01	-3.2E-01	-2.6E-01	-3.4E-01	-3.3E-01	-3.7E-01	-3.4E-01	-1.5E+00	-3.1E-01	-7.2E-01
Beryllium	water	-4.0E+04	-4.2E+04	-5.6E+04	-5.0E+04	-6.3E+04	-5.2E+04	-5.0E+04	-5.8E+04	-4.9E+04	-4.3E+04	-2.9E+04	-5.2E+04
Cadmium	water	8.5E+01	2.3E+02	2.5E+01	4.8E+01	3.8E+01	1.4E+01	7.3E+00	-5.0E-01	6.8E+00	1.2E+01	6.1E+01	3.4E+01
Cadmium, ion	water	-1.0E+02	-1.1E+02	-1.0E+02	-1.3E+02	-1.3E+02	-1.1E+02	-1.1E+02	-1.1E+02	-1.6E+02	-1.4E+02	-1.5E+02	-1.2E+02
Chlorinated solvents, unspecified	water	-8.2E-01	-6.6E-01	-9.2E-01	-1.4E+00	-1.3E+00	-1.1E+00	-1.1E+00	-1.3E+00	-1.1E+00	-1.8E+00	-1.3E+00	-1.5E+00
Chloroform [Trichloromethane]	water	-7.0E-04	4.3E-05	-2.9E-04	-8.7E-04	-6.9E-04	-9.3E-04	-8.9E-04	-1.0E-03	-9.5E-04	-4.6E-03	-8.6E-04	-2.1E-03
Chromium	water	1.4E+02	8.1E+01	5.6E+01	1.1E+02	7.3E+01	5.5E+01	4.1E+01	4.2E+01	5.4E+01	3.7E+01	1.1E+02	6.4E+01
Chromium VI	water	-3.0E+03	-3.0E+03	-4.9E+03	-4.3E+03	-5.4E+03	-4.4E+03	-4.1E+03	-5.1E+03	-4.2E+03	-3.2E+03	-4.4E+03	-4.4E+03
Cobalt	water	-1.9E+03	-1.5E+03	-3.0E+03	-2.4E+03	-3.0E+03	-2.7E+03	-2.5E+03	-2.9E+03	-2.6E+03	-2.2E+03	1.5E+03	-2.8E+03

Copper	water	8.7E+01	3.7E+02	1.6E+01	5.7E+01	2.2E+01	5.4E+01	2.7E+01	3.9E+01	4.8E+01	4.5E+01	1.0E+02	5.5E+01
Copper, ion	water	1.1E+03	1.1E+03	1.1E+03	1.0E+03	1.2E+03	1.1E+03	1.1E+03	1.1E+03	1.1E+03	1.0E+03	1.2E+03	1.1E+03
Di(2-ethylhexyl)phthalate (DEHP)	water	3.5E+01	8.0E-01	1.6E+01	1.9E+01	2.0E+01	7.7E+00	4.6E+00	3.8E+00	3.7E+00	9.3E+00	4.6E+00	2.2E+01
Dichloromethane	water	-1.7E+00	-2.5E+00	-3.2E+00	-3.0E+00	-7.2E-01	-3.1E+00	-2.9E+00	-3.6E+00	-2.8E+00	-2.0E+00	-3.3E+00	-2.8E+00
Dichromate	water	-2.9E+00	-3.0E+00	-4.5E+00	-4.0E+00	-5.1E+00	-4.1E+00	-3.9E+00	-4.7E+00	-3.9E+00	-2.9E+00	-4.1E+00	-4.1E+00
Ethane, 1,1,1-trichloro-, HCFC-140	water	-7.2E-07	-8.5E-07	-7.0E-07	-8.3E-07	-9.6E-07	-7.7E-07	-7.5E-07	-7.9E-07	-1.2E-06	-7.2E-07	-1.1E-06	-7.7E-07
Ethene	water	-4.9E+00	-5.0E+00	-5.1E+00	-5.0E+00	-6.2E+00	-5.1E+00	-5.0E+00	-5.1E+00	-5.0E+00	-5.0E+00	-6.0E+00	-5.0E+00
Ethene, chloro-	water	-1.4E+00	-1.4E+00	-2.1E+00	-1.9E+00	-2.4E+00	-1.9E+00	-1.8E+00	-2.3E+00	-1.9E+00	-1.4E+00	-2.0E+00	-2.0E+00
Ethene, tetrachloro-	water	4.2E-07	3.6E-07	4.4E-07	4.1E-07	3.9E-07	4.1E-07	4.2E-07	4.1E-07	3.6E-07	4.2E-07	3.9E-07	4.2E-07
Ethene, trichloro-	water	3.7E-01	8.2E-03	1.8E-01	3.4E-01	2.8E-01	1.1E-01	8.5E-02	7.6E-02	9.5E-02	1.5E-01	4.7E-02	2.0E-01
Ethylbenzene	water	-1.7E+00	-1.9E+00	-3.1E+00	-2.9E+00	-3.8E+00	-3.0E+00	-2.8E+00	-3.5E+00	-3.2E+00	-1.9E+00	-3.3E+00	-2.7E+00
Ethylene dichloride	water	-3.0E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.6E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.3E+02	-3.5E+02	-3.1E+02
Ethylene oxide	water	-5.2E+02	-5.1E+02	-5.1E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.4E+02	-5.2E+02	-5.3E+02
Formaldehyde	water	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-6.0E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-5.9E-01	-4.9E-01
Fungicides, unspecified	water	8.5E-03	8.5E-03	8.5E-03	8.5E-03	1.0E-02	8.5E-03	8.5E-03	8.5E-03	8.5E-03	8.4E-03	1.0E-02	8.4E-03
Herbicides, unspecified	water	-4.0E-06	-1.4E-07	-1.9E-06	-4.8E-06	-3.8E-06	-5.1E-06	-4.9E-06	-5.6E-06	-5.1E-06	-2.3E-05	-4.7E-06	-1.1E-05
Insecticides, unspecified	water	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Lead	water	1.8E+03	1.7E+03	1.2E+03	1.4E+03	1.4E+03	1.8E+03	1.1E+03	1.0E+03	1.0E+03	1.0E+03	3.6E+03	1.2E+03
Mercury	water	-2.0E+02	-6.1E+02	-3.4E+02	-9.6E+01	-3.9E+02	-5.5E+02	-5.0E+02	-5.5E+02	-5.9E+02	-6.3E+02	1.5E+02	-5.6E+02
Metals (unspecified)	water	-5.9E-01	-5.8E-01	-5.7E-01	-5.9E-01	-5.8E-01	-5.9E-01	-5.9E-01	-5.9E-01	-6.0E-01	-5.9E-01	-5.9E-01	-5.9E-01
Molybdenum	water	-9.2E+04	3.8E+05	-1.2E+05	-1.1E+05	-1.3E+05	-1.1E+05	-1.1E+05	-1.2E+05	-1.0E+05	-1.0E+05	-1.2E+05	-1.1E+05
m-Xylene	water	6.2E-03	6.1E-03	6.4E-03	6.3E-03	6.3E-03	6.3E-03	6.3E-03	6.4E-03	6.1E-03	6.2E-03	6.2E-03	6.3E-03
Nickel	water	2.5E+04	7.3E+03	1.1E+04	2.0E+04	1.1E+04	1.5E+04	1.2E+04	1.1E+04	1.4E+04	1.5E+04	6.9E+04	1.5E+04
Nickel, ion	water	2.1E+03	8.9E+03	-6.3E+02	2.3E+03	1.0E+04	1.2E+03	3.0E+03	4.5E+03	2.4E+03	-2.6E+03	4.1E+03	-1.9E+03
o-Xylene	water	2.9E-04	2.9E-04	4.6E-04	4.0E-04	5.2E-04	4.2E-04	3.9E-04	4.8E-04	4.0E-04	2.9E-04	4.2E-04	4.1E-04
PAH, polycyclic aromatic hydrocarbons	water	-1.5E+05	-1.5E+05	-2.6E+05	-2.4E+05	-3.2E+05	-2.5E+05	-2.3E+05	-2.8E+05	-2.7E+05	-1.6E+05	-2.7E+05	-2.3E+05
Phenol	water	-5.1E-01	-6.0E-01	-8.5E-01	-1.0E+00	-1.0E+00	-8.5E-01	-8.0E-01	-9.8E-01	-9.0E-01	-6.0E-01	-1.1E+00	-7.6E-01
Phthalate, dibutyl-	water	1.4E-08	4.4E-09	1.6E-08	8.5E-09	8.4E-10	1.1E-08	1.2E-08	1.0E-08	-1.1E-08	1.4E-08	-6.7E-09	1.1E-08
Propylene oxide	water	1.7E+03	1.8E+03	1.6E+03	1.6E+03	2.0E+03	3.0E+03	3.1E+03	1.6E+03	2.0E+03	1.6E+03	1.6E+03	1.6E+03

Selenium	water	-1.0E+06	-1.1E+06	-1.6E+06	-1.4E+06	-1.8E+06	-1.5E+06	-1.4E+06	-1.7E+06	-1.4E+06	-1.1E+06	-1.3E+06	-1.5E+06
Thallium	water	-3.8E+04	-4.8E+04	-7.3E+04	-6.8E+04	-7.6E+04	-6.1E+04	-5.7E+04	-7.1E+04	-5.2E+04	-4.7E+04	-5.6E+04	-6.2E+04
Tin, ion	water	6.6E-01	6.6E-01	6.1E-01	5.9E-01	7.3E-01	6.3E-01	6.4E-01	6.3E-01	6.6E-01	6.4E-01	1.1E+00	6.3E-01
Toluene	water	-3.2E+00	-3.6E+00	-5.9E+00	-5.5E+00	-7.2E+00	-5.8E+00	-5.3E+00	-6.7E+00	-6.1E+00	-3.7E+00	-6.2E+00	-5.1E+00
Tributyltin compounds	water	-2.2E+03	-2.5E+03	-3.4E+03	-3.2E+03	-3.9E+03	-3.0E+03	-2.8E+03	-3.3E+03	-2.9E+03	-2.3E+03	-3.0E+03	-3.0E+03
Vanadium, ion	water	-4.3E+06	-4.3E+06	-7.1E+06	-6.2E+06	-8.0E+06	-6.3E+06	-6.0E+06	-7.4E+06	-6.0E+06	-4.5E+06	-6.4E+06	-6.4E+06
Xylene - all isomers [Dimethylbenzene]	water	-3.7E+00	-4.1E+00	-6.8E+00	-6.3E+00	-8.3E+00	-6.6E+00	-6.1E+00	-7.7E+00	-7.0E+00	-4.2E+00	-7.2E+00	-5.9E+00
Zinc	water	7.3E+02	-1.1E+02	1.2E+02	4.3E+02	3.8E+02	4.7E+02	1.9E+02	2.5E+02	3.5E+02	3.0E+02	1.6E+03	3.6E+02
2,4-D	soil	5.3E+01	5.3E+01	5.2E+01	5.3E+01	6.5E+01	5.3E+01	5.3E+01	5.2E+01	5.3E+01	5.2E+01	6.3E+01	5.2E+01
Antimony	soil	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.9E-01	8.1E-01	8.4E-01	8.3E-01
Arsenic	soil	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.0E+06	3.4E+05	1.9E+06	3.4E+05
Atrazine	soil	-6.4E-04	-5.8E-04	-6.3E-04	-7.3E-04	-7.9E-04	-7.0E-04	-6.9E-04	-7.2E-04	-9.6E-04	-1.0E-03	-9.4E-04	-8.1E-04
Barium	soil	-7.1E+03	-1.1E+04	-1.4E+04	-1.3E+04	-3.1E+03	-1.3E+04	-1.2E+04	-1.5E+04	-1.2E+04	-8.4E+03	-1.4E+04	-1.2E+04
Bentazone	soil	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.4E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.3E+00	1.9E+00
Cadmium	soil	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	1.3E+05	8.3E+03	8.3E+04	8.3E+03
Chlorothalonil	soil	5.5E+01	5.5E+01	5.4E+01	5.4E+01	5.4E+01	5.4E+01	5.4E+01	5.4E+01	5.5E+01	5.5E+01	5.4E+01	5.4E+01
Chromium	soil	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.4E+06	1.5E+05	9.3E+05	1.5E+05
Chromium VI	soil	-1.1E+05	-1.1E+05	-1.7E+05	-1.5E+05	-1.9E+05	-1.5E+05	-1.5E+05	-1.8E+05	-1.5E+05	-1.1E+05	-1.6E+05	-1.5E+05
Cobalt	soil	-1.5E+01	-1.5E+01	-1.4E+01	-1.2E+01	-1.5E+01	-1.4E+01	-1.5E+01	-1.3E+01	-1.3E+01	-1.4E+01	-1.7E+01	-1.4E+01
Copper	soil	-7.8E+03	-7.8E+03	-8.1E+03	-8.0E+03	-8.3E+03	-8.0E+03	-8.0E+03	-8.2E+03	5.4E+04	-7.8E+03	3.0E+04	-8.0E+03
Cypermethrin	soil	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03
Dinoseb	soil	-1.3E-01	-1.3E-01	-3.3E-01	-1.8E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.8E-01	-2.1E-01	-1.6E-01	-3.1E-01	-1.4E-01
Glyphosate	soil	5.9E-02	5.9E-02	5.8E-02	5.8E-02	7.2E-02	5.8E-02	5.8E-02	5.8E-02	5.9E-02	5.8E-02	7.0E-02	5.8E-02
Lead	soil	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.0E+06	5.9E+05	3.3E+06	5.9E+05
Linuron	soil	3.2E+02	3.2E+02	3.2E+02	3.2E+02	4.0E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.8E+02	3.2E+02
Mercury	soil	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.8E+04	1.9E+03	1.2E+04	1.9E+03
Metazachlor	soil	1.3E+02	7.2E+01	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.2E+02	1.3E+02
Metolachlor	soil	1.6E+02	1.6E+02	1.6E+02	1.6E+02	2.0E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.9E+02	1.6E+02
Molybdenum	soil	-1.9E+01	-1.8E+01	-1.7E+01	-1.5E+01	-1.9E+01	-1.8E+01	-1.9E+01	-1.6E+01	-1.6E+01	-2.0E+01	-2.1E+01	-1.8E+01
Nickel	soil	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	5.5E+05	6.3E+04	3.6E+05	6.3E+04

Pirimicarb	soil	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.9E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.7E-01	3.1E-01
Selenium	soil	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03
Thallium	soil	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.1E-03	8.2E-03	8.1E-03	8.2E-03
Tin	soil	-4.8E-04	1.1E-03	-5.0E-04	-2.0E-03	-2.7E-03	-2.2E-03	-1.9E-03	-3.1E-03	-1.9E-03	-1.3E-02	-1.5E-03	-6.4E-03
Vanadium	soil	-3.0E+02	-2.9E+02	-2.7E+02	-2.4E+02	-3.0E+02	-2.7E+02	-2.9E+02	-2.5E+02	-2.5E+02	-2.7E+02	-3.4E+02	-2.6E+02
Zinc	soil	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.7E+05	1.5E+04	1.1E+05	1.5E+04

Table 30: Freshwater ecotoxicity impacts by pollutant (kg 1,4-DCB equivalents)

Substances	**Compartment**	**Landfill**	**Incineration**	**Haase**	**Arrowbio**	**Global renewables**	**Ecodeco**	**Entsorga**	**Herhof**	**Bedminster**	**Linde**	**SRS**	**VKW**
Total		-9.3E+06	-9.4E+06	-1.6E+07	-1.4E+07	-1.7E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.0E+07	-9.8E+06	-1.1E+07	-1.4E+07
Acenaphthene	air	-1.5E-02	-2.6E-02	-1.8E-02	-2.5E-02	-1.7E-02	-1.0E-02	-8.6E-03	-7.2E-03	-6.5E-03	-8.5E-03	-9.4E-03	-1.3E-02
Acrolein	air	-1.2E+01	-1.1E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01
Antimony	air	-1.5E+00	1.3E+01	-1.3E+00	-1.0E+00	-1.4E+00	-6.1E-01	-8.9E-01	-1.6E+00	-5.0E-01	-6.3E-01	-5.2E-01	-8.0E-01
Arsenic	air	-1.1E+02	-4.8E+01	-1.4E+02	-1.4E+02	-1.6E+02	-1.1E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.5E+02
Barium	air	-1.7E+02	-2.0E+02	-2.3E+02	-2.2E+02	-2.4E+02	-2.1E+02	-2.1E+02	-2.3E+02	-1.9E+02	-1.9E+02	-2.0E+02	-2.1E+02
Benzene	air	-7.3E-03	-1.2E-02	-9.1E-03	-9.4E-03	-9.7E-03	-7.3E-03	-7.2E-03	-7.9E-03	-6.0E-03	-5.9E-03	-7.0E-03	-7.2E-03
Benzene, ethyl-	air	-6.0E-04	-6.2E-04	-8.5E-04	1.6E-02	-1.0E-03	-8.3E-04	-7.9E-04	-9.1E-04	-8.5E-04	-6.3E-04	-9.1E-04	-7.7E-04
Benzene, pentachloro-	air	4.9E-04	5.1E-04	5.3E-04	5.1E-04	6.1E-04	5.2E-04	5.1E-04	5.3E-04	5.2E-04	4.9E-04	5.6E-04	5.2E-04
Benzo(a)pyrene	air	-5.1E+02	-4.9E+02	-8.3E+02	-7.2E+02	-9.3E+02	-7.4E+02	-7.0E+02	-8.7E+02	-7.1E+02	-5.2E+02	-7.5E+02	-7.4E+02
Beryllium	air	-3.0E+02	-3.2E+02	-3.7E+02	-3.4E+02	-3.4E+02	-4.0E+02	-4.1E+02	-4.2E+02	-3.6E+02	-4.0E+02	-3.4E+02	-3.4E+02
Butadiene [1,3-Butadiene]	air	1.9E-05	1.8E-05	1.9E-05	1.8E-05	1.6E-05	1.9E-05	2.0E-05	1.9E-05	1.5E-05	2.0E-05	1.6E-05	1.8E-05
Cadmium	air	-3.4E+02	-1.3E+02	-4.7E+02	-4.5E+02	-5.3E+02	-3.9E+02	-3.8E+02	-4.5E+02	-4.0E+02	-4.0E+02	-4.3E+02	-4.6E+02
Carbon disulphide	air	1.9E+00	2.4E+00	3.8E+00	3.4E+00	4.4E+00	3.2E+00	3.1E+00	4.2E+00	2.5E+00	2.0E+00	3.1E+00	3.1E+00
Carbon tetrachloride [Tetrachloromethane]	air	4.4E-05	9.8E-06	1.0E-04	3.8E-05	2.7E-05	1.7E-05	5.4E-06	2.4E-06	4.1E-06	-9.6E-05	1.5E-06	-1.6E-06
Chlorinated Matter (unspecified, as Cl)	air	-2.7E-11	-9.0E-13	-1.3E-11	-3.3E-11	-2.6E-11	-3.5E-11	-3.4E-11	-3.9E-11	-3.5E-11	-1.6E-10	-3.2E-11	-7.6E-11
Chloroform [Trichloromethane]	air	1.6E-05	-1.8E-07	8.9E-06	1.3E-05	9.2E-06	6.7E-06	2.5E-06	1.5E-06	2.1E-06	4.7E-06	1.2E-06	1.3E-05
Chromium VI	air	-4.8E-01	9.9E-02	2.5E+00	4.0E+00	4.7E+00	1.5E+00	1.5E+00	2.3E+00	3.8E+00	3.9E+00	3.8E+00	3.5E+00
Cobalt	air	-6.7E+02	1.2E+02	-8.5E+02	-8.3E+02	-8.5E+02	-7.4E+02	-7.1E+02	-7.4E+02	-6.7E+02	-7.8E+02	-6.8E+02	-8.0E+02
Copper	air	-8.7E+03	-7.5E+03	-1.3E+04	-1.2E+04	-1.5E+04	-1.2E+04	-1.1E+04	-1.3E+04	-1.1E+04	-8.7E+03	-1.2E+04	-1.2E+04

Dichloromethane	air	4.5E-06	-2.9E-06	1.4E-06	3.1E-06	1.5E-06	3.4E-07	-1.6E-06	-2.0E-06	-1.8E-06	-4.8E-07	-2.1E-06	3.1E-06
Dioxins and furans- as ITEQ	air	3.5E-02	2.7E+01	2.9E+00	7.9E-02	8.2E-02	9.7E+00	1.2E+01	1.2E+01	4.7E+00	8.3E+00	8.8E+00	1.2E+00
Dioxins and furans- as WHO TEQ	air	-2.6E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.7E-01	-2.6E-01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.7E+02	-2.8E+02	-2.8E+02	-2.8E+02	-3.5E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.7E+02	-3.3E+02	-2.8E+02
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.3E-03	2.1E-05	3.6E-04	1.0E-03	4.8E-04	6.8E-04	3.8E-04	6.1E-04	6.4E-04	4.0E-04	1.2E-04	9.2E-04
Ethane, 1,2-dichloro-	air	-7.5E-04	-8.0E-04	-8.6E-04	-8.1E-04	-1.0E-03	-8.3E-04	-8.3E-04	-8.6E-04	-8.3E-04	-8.7E-04	-9.8E-04	-8.5E-04
Ethylene [Ethene]	air	3.3E-10	8.8E-11	-1.6E-10	-1.3E-10	7.6E-11	-1.9E-10	-1.8E-10	-3.1E-10	-1.2E-10	3.4E-11	3.2E-10	-7.9E-11
Ethylene oxide [1,2-Epoxyethane]	air	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01
Formaldehyde [Methanal]	air	-8.9E+02	-1.1E+03	-1.1E+03	-1.1E+03	-1.2E+03	-1.0E+03	-1.0E+03	-1.1E+03	-9.9E+02	-9.1E+02	-1.0E+03	-1.1E+03
Hexachlorobenzene	air	3.5E-04	9.7E-04	4.0E-04	7.9E-04	1.9E-03	3.8E-04	5.1E-04	8.4E-04	4.3E-04	3.1E-04	8.4E-04	3.3E-04
Hydrocarbons (unspecified)	air	-3.0E-10	4.8E-09	-2.8E-10	-3.6E-10	-4.4E-10	-3.3E-10	-3.2E-10	-3.4E-10	-5.7E-10	-3.0E-10	-5.4E-10	-3.2E-10
Hydrogen fluoride	air	-7.0E+03	-8.2E+03	-1.1E+04	-1.0E+04	-1.2E+04	-1.0E+04	-9.6E+03	-1.2E+04	-9.7E+03	-7.2E+03	-1.0E+04	-9.9E+03
Lead	air	-2.0E+00	-4.4E+00	9.5E+00	1.7E+00	3.9E+00	7.8E+00	7.4E+00	1.4E+01	5.4E+00	-3.8E+00	8.2E+00	3.3E+00
Mercury	air	-3.3E+02	3.0E+02	-2.5E+02	-3.4E+02	-1.8E+02	-1.3E+02	-1.4E+02	-1.3E+02	-1.2E+02	-3.9E+01	-1.3E+02	-2.4E+02
Methyl bromide [Bromomethane]	air	2.0E-10	2.0E-10	3.2E-10	2.8E-10	3.6E-10	2.9E-10	2.7E-10	3.4E-10	2.8E-10	2.0E-10	2.9E-10	2.9E-10
Molybdenum	air	-2.8E+01	-3.3E+01	-4.0E+01	-4.0E+01	-3.6E+01	-3.5E+01	-3.4E+01	-3.8E+01	-3.1E+01	-3.7E+01	-2.9E+01	-3.7E+01
m-Xylene	air	-3.3E-04	-3.3E-04	-3.3E-04	-3.2E-04	-3.9E-04	-3.3E-04	-3.3E-04	-3.3E-04	-3.3E-04	-3.3E-04	-3.9E-04	-3.3E-04
Nickel	air	-1.4E+04	-7.0E+03	-1.8E+04	-1.7E+04	-1.9E+04	-1.7E+04	-1.5E+04	-1.9E+04	-1.5E+04	-1.4E+04	-1.4E+04	-1.7E+04
o-Xylene	air			8.2E-03		8.2E-03	3.4E-02	1.5E-02	1.5E-02	1.2E-02	1.2E-02	1.2E-02	1.2E-02
PAH, polycyclic aromatic hydrocarbons	air	-3.2E+04	-3.2E+04	-5.2E+04	-4.5E+04	-5.8E+04	-4.6E+04	-4.3E+04	-5.4E+04	-4.4E+04	-3.1E+04	-4.6E+04	-4.6E+04
Pentachlorophenol	air	-8.6E-01	2.7E-01	-9.1E-01	-9.0E-01	-1.1E+00	-9.3E-01	-9.4E-01	-9.6E-01	-9.1E-01	-1.0E+00	-1.1E+00	-9.3E-01
Phenol	air	2.5E+00	3.6E+00	3.1E+00	2.4E+00	3.5E+00	2.5E+00	2.5E+00	2.4E+00	2.5E+00	2.3E+00	3.4E+00	2.4E+00
Propylene oxide	air	1.3E-02	1.3E-02	1.2E-02	1.2E-02	1.5E-02	2.2E-02	2.3E-02	1.1E-02	1.4E-02	1.1E-02	1.1E-02	1.1E-02
Selenium	air	-1.2E+03	-1.5E+03	-1.7E+03	-1.7E+03	-1.7E+03	-1.4E+03	-1.3E+03	-1.4E+03	-1.2E+03	-1.2E+03	-1.3E+03	-1.4E+03
Sodium dichromate	air	-1.4E-02	-3.2E-02	-5.3E-01	-3.5E-01	-4.9E-01	-3.9E-01	-3.2E-01	-5.9E-01	-3.4E-01	-2.8E-02	-2.2E-01	-3.9E-01
Styrene	air	-1.1E-06	-9.5E-07	1.8E-03	1.7E-03	1.7E-03	5.7E-03	2.0E-03	2.0E-03	2.6E-03	2.7E-03	2.7E-03	2.5E-03
Tetrachloroethylene	air	7.7E-05	-6.6E-06	4.1E-05	6.1E-05	4.3E-05	2.9E-05	7.9E-06	2.8E-06	5.6E-06	2.0E-05	1.6E-06	6.0E-05
Thallium	air	-2.2E+01	-2.3E+01	4.6E+02	4.6E+02	4.6E+02	2.2E+02	2.2E+02	2.2E+02	6.6E+02	6.5E+02	6.6E+02	6.7E+02

Tin	air	-9.2E-01	1.5E+01	-1.4E+00	-1.2E+00	-1.5E+00	-1.3E+00	-1.2E+00	-1.3E+00	-1.2E+00	-1.1E+00	-1.3E+00	-1.3E+00
Toluene	air	-1.8E-03	-4.8E-03	1.4E-02	8.2E-03	8.1E-03	4.3E-02	3.3E-02	3.3E-02	2.3E-02	3.1E-02	3.2E-02	1.6E-02
Trichloroethylene	air	9.7E-05	1.2E-06	5.6E-05	7.8E-05	5.8E-05	4.2E-05	1.8E-05	1.2E-05	1.5E-05	3.2E-05	1.1E-05	7.8E-05
Vanadium	air	-4.7E+04	-4.5E+04	-5.9E+04	-5.8E+04	-5.7E+04	-5.6E+04	-5.5E+04	-6.0E+04	-5.3E+04	-7.0E+04	-5.1E+04	-6.2E+04
Vinyl chloride	air	-1.9E-06	-2.3E-06	-3.4E-06	-2.8E-06	-3.8E-06	-3.1E-06	-3.0E-06	-3.7E-06	-3.1E-06	-2.3E-06	-3.3E-06	-3.0E-06
Zinc	air	4.5E+03	4.5E+03	7.4E+03	6.4E+03	8.3E+03	6.6E+03	6.2E+03	7.7E+03	6.3E+03	4.4E+03	6.6E+03	6.6E+03
Acenaphthene	water	-1.6E+01	-1.7E+01	-2.9E+01	-2.7E+01	-3.5E+01	-2.8E+01	-2.6E+01	-3.2E+01	-2.9E+01	-1.8E+01	-3.0E+01	-2.5E+01
Acenaphthylene	water	1.7E-02	-7.6E-01	-6.1E-01	-1.1E+00	-2.1E+00	-9.5E-01	-7.4E-01	-1.3E+00	-2.7E+00	-9.6E-02	-2.4E+00	-7.5E-01
Antimony	water	-3.3E+02	-1.1E+01	-3.6E+02	-8.9E+02	-4.4E+02	-3.6E+02	-3.5E+02	-3.7E+02	-3.5E+02	-3.8E+02	-5.2E+02	-3.7E+02
Arsenic	water	6.1E+03	2.3E+02	4.7E+03	5.8E+03	4.9E+03	1.9E+03	2.3E+03	5.0E+02	1.7E+03	2.5E+03	2.4E+03	2.7E+03
Arsenic, ion	water	-1.6E+04	-1.6E+04	-2.5E+04	-2.2E+04	-2.8E+04	-2.3E+04	-2.2E+04	-2.6E+04	-2.2E+04	-1.7E+04	-2.3E+04	-2.3E+04
Barite	water	-1.2E+05	-3.3E+05	-1.8E+05	-2.7E+05	1.6E+05	-7.4E+04	-5.2E+04	-3.6E+04	1.3E+04	-4.5E+04	-6.0E+04	-1.1E+05
Barium	water	-5.5E+04	2.6E+04	-8.3E+04	-7.6E+04	-9.6E+04	-8.0E+04	-7.6E+04	-9.0E+04	-7.9E+04	-6.4E+04	-3.4E+04	-7.7E+04
Benzene	water	-2.1E+00	-2.2E+00	-2.6E+00	-2.5E+00	-3.2E+00	-2.6E+00	-2.5E+00	-2.7E+00	-2.6E+00	-2.2E+00	-2.9E+00	-2.5E+00
Benzene, chloro-	water	-9.2E-03	-7.2E-04	-4.7E-03	-1.1E-02	-9.0E-03	-1.2E-02	-1.1E-02	-1.3E-02	-1.2E-02	-5.2E-02	-1.1E-02	-2.5E-02
Beryllium	water	-2.2E+05	-2.3E+05	-3.1E+05	-2.8E+05	-3.5E+05	-2.8E+05	-2.7E+05	-3.2E+05	-2.7E+05	-2.4E+05	-1.6E+05	-2.8E+05
Cadmium	water	3.2E+03	8.5E+03	9.5E+02	1.8E+03	1.4E+03	5.4E+02	2.8E+02	-1.9E+01	2.6E+02	4.7E+02	2.3E+03	1.3E+03
Cadmium, ion	water	-3.9E+03	-4.1E+03	-3.9E+03	-4.8E+03	-4.8E+03	-4.3E+03	-4.2E+03	-4.3E+03	-6.0E+03	-5.4E+03	-5.7E+03	-4.7E+03
Chlorinated solvents, unspecified	water	-8.7E-02	-7.0E-02	-9.8E-02	-1.5E-01	-1.4E-01	-1.2E-01	-1.1E-01	-1.4E-01	-1.2E-01	-1.9E-01	-1.4E-01	-1.5E-01
Chloroform [Trichloromethane]	water	-2.1E-06	1.3E-07	-8.9E-07	-2.6E-06	-2.1E-06	-2.8E-06	-2.7E-06	-3.1E-06	-2.9E-06	-1.4E-05	-2.6E-06	-6.4E-06
Chromium	water	2.6E+02	1.5E+02	1.0E+02	2.1E+02	1.4E+02	1.0E+02	7.6E+01	7.8E+01	1.0E+02	7.0E+01	2.0E+02	1.2E+02
Chromium VI	water	-1.4E+04	-1.3E+04	-2.2E+04	-1.9E+04	-2.4E+04	-2.0E+04	-1.8E+04	-2.3E+04	-1.9E+04	-1.4E+04	-2.0E+04	-2.0E+04
Cobalt	water	-6.2E+04	-4.7E+04	-9.5E+04	-7.6E+04	-9.6E+04	-8.6E+04	-7.8E+04	-9.3E+04	-8.2E+04	-6.9E+04	4.9E+04	-9.0E+04
Copper	water	4.3E+04	1.8E+05	8.2E+03	2.9E+04	1.1E+04	2.7E+04	1.4E+04	1.9E+04	2.4E+04	2.2E+04	5.1E+04	2.8E+04
Copper, ion	water	5.3E+05	5.3E+05	5.3E+05	5.2E+05	6.2E+05	5.3E+05	5.3E+05	5.4E+05	5.4E+05	5.2E+05	5.9E+05	5.3E+05
Di(2-ethylhexyl)phthalate (DEHP)	water	1.5E+01	3.3E-01	6.5E+00	8.0E+00	8.2E+00	3.2E+00	1.9E+00	1.6E+00	1.5E+00	3.9E+00	1.9E+00	8.9E+00
Dichloromethane	water	-1.1E-02	-1.6E-02	-2.1E-02	-1.9E-02	-4.7E-03	-2.0E-02	-1.8E-02	-2.3E-02	-1.8E-02	-1.3E-02	-2.1E-02	-1.8E-02
Dichromate	water	-1.3E+01	-1.3E+01	-2.0E+01	-1.8E+01	-2.3E+01	-1.8E+01	-1.7E+01	-2.1E+01	-1.7E+01	-1.3E+01	-1.8E+01	-1.8E+01
Ethane, 1,1,1-trichloro-, HCFC-140	water	-4.2E-09	-5.0E-09	-4.1E-09	-4.9E-09	-5.6E-09	-4.5E-09	-4.4E-09	-4.6E-09	-6.9E-09	-4.2E-09	-6.7E-09	-4.5E-09

Ethene	water	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.1E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.0E-01	-1.7E-01
Ethene, chloro-	water	-2.4E-04	-2.5E-04	-3.9E-04	-3.4E-04	-4.3E-04	-3.5E-04	-3.3E-04	-4.0E-04	-3.3E-04	-2.6E-04	-3.5E-04	-3.5E-04
Ethene, tetrachloro-	water	4.6E-08	3.9E-08	4.8E-08	4.5E-08	4.2E-08	4.5E-08	4.5E-08	4.5E-08	3.9E-08	4.6E-08	4.2E-08	4.5E-08
Ethene, trichloro-	water	9.6E-04	2.2E-05	4.8E-04	8.9E-04	7.3E-04	2.8E-04	2.2E-04	2.0E-04	2.5E-04	4.0E-04	1.2E-04	5.3E-04
Ethylbenzene	water	-1.1E+00	-1.2E+00	-2.0E+00	-1.9E+00	-2.4E+00	-2.0E+00	-1.8E+00	-2.3E+00	-2.1E+00	-1.2E+00	-2.1E+00	-1.8E+00
Ethylene dichloride	water	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.9E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.6E-01	-2.8E-01	-2.4E-01
Ethylene oxide	water	-4.4E-01	-4.3E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.6E-01	-4.4E-01	-4.5E-01
Formaldehyde	water	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.6E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.4E+03	-3.7E+03
Fungicides, unspecified	water	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.7E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.5E-03	4.6E-03
Herbicides, unspecified	water	-3.4E-05	-1.2E-06	-1.7E-05	-4.1E-05	-3.3E-05	-4.4E-05	-4.2E-05	-4.8E-05	-4.4E-05	-2.0E-04	-4.1E-05	-9.5E-05
Insecticides, unspecified	water	8.7E+00	8.7E+00	8.7E+00	8.7E+00	1.1E+01	8.7E+00	8.7E+00	8.7E+00	8.7E+00	8.6E+00	1.0E+01	8.7E+00
Lead	water	6.7E+02	6.5E+02	4.5E+02	5.3E+02	5.2E+02	6.8E+02	4.1E+02	3.8E+02	3.9E+02	4.0E+02	1.4E+03	4.6E+02
Mercury	water	-1.2E+02	-3.7E+02	-2.1E+02	-5.9E+01	-2.4E+02	-3.4E+02	-3.1E+02	-3.4E+02	-3.6E+02	-3.9E+02	9.1E+01	-3.4E+02
Metals (unspecified)	water	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02
Molybdenum	water	-6.6E+03	2.7E+04	-8.4E+03	-8.0E+03	-9.3E+03	-7.8E+03	-7.6E+03	-8.4E+03	-7.3E+03	-7.2E+03	-8.4E+03	-7.9E+03
m-Xylene	water	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02
Nickel	water	1.7E+05	5.2E+04	7.6E+04	1.4E+05	7.5E+04	1.0E+05	8.3E+04	7.9E+04	9.6E+04	1.1E+05	4.9E+05	1.1E+05
Nickel, ion	water	1.5E+04	6.4E+04	-4.5E+03	1.6E+04	7.3E+04	8.5E+03	2.1E+04	3.2E+04	1.7E+04	-1.8E+04	2.9E+04	-1.3E+04
o-Xylene	water	3.8E-04	3.8E-04	6.1E-04	5.3E-04	6.9E-04	5.4E-04	5.1E-04	6.3E-04	5.2E-04	3.8E-04	5.5E-04	5.4E-04
PAH, polycyclic aromatic hydrocarbons	water	-1.4E+04	-1.5E+04	-2.5E+04	-2.3E+04	-3.0E+04	-2.4E+04	-2.2E+04	-2.7E+04	-2.6E+04	-1.5E+04	-2.6E+04	-2.2E+04
Phenol	water	-2.5E+03	-2.9E+03	-4.1E+03	-4.8E+03	-5.0E+03	-4.1E+03	-3.9E+03	-4.7E+03	-4.3E+03	-2.9E+03	-5.1E+03	-3.7E+03
Phthalate, dibutyl-	water	2.1E-06	6.5E-07	2.4E-06	1.3E-06	1.2E-07	1.6E-06	1.8E-06	1.5E-06	-1.7E-06	2.0E-06	-9.8E-07	1.7E-06
Propylene oxide	water	2.6E+00	2.6E+00	2.4E+00	2.5E+00	3.1E+00	4.5E+00	4.7E+00	2.3E+00	2.9E+00	2.3E+00	2.4E+00	2.4E+00
Selenium	water	-4.5E+04	-4.6E+04	-7.1E+04	-6.3E+04	-8.0E+04	-6.4E+04	-6.1E+04	-7.4E+04	-6.1E+04	-4.7E+04	-5.9E+04	-6.4E+04
Thallium	water	-1.1E+03	-1.4E+03	-2.1E+03	-2.0E+03	-2.2E+03	-1.8E+03	-1.7E+03	-2.1E+03	-1.5E+03	-1.4E+03	-1.6E+03	-1.8E+03
Tin, ion	water	1.9E+02	1.9E+02	1.8E+02	1.7E+02	2.1E+02	1.9E+02	1.9E+02	1.8E+02	1.9E+02	1.9E+02	3.3E+02	1.8E+02
Toluene	water	-3.0E+00	-3.4E+00	-5.6E+00	-5.2E+00	-6.8E+00	-5.5E+00	-5.0E+00	-6.3E+00	-5.7E+00	-3.5E+00	-5.9E+00	-4.9E+00
Tributyltin compounds	water	-2.9E+05	-3.3E+05	-4.6E+05	-4.3E+05	-5.2E+05	-4.0E+05	-3.8E+05	-4.5E+05	-3.8E+05	-3.0E+05	-4.0E+05	-4.1E+05
Vanadium, ion	water	-9.3E+06	-9.3E+06	-1.5E+07	-1.3E+07	-1.7E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.3E+07	-9.7E+06	-1.4E+07	-1.4E+07
Xylene - all isomers [Dimethylbenzene]	water	-4.9E+00	-5.5E+00	-9.1E+00	-8.4E+00	-1.1E+01	-8.9E+00	-8.2E+00	-1.0E+01	-9.3E+00	-5.6E+00	-9.5E+00	-7.9E+00

Zinc	water	6.0E+04	-8.9E+03	9.5E+03	3.6E+04	3.2E+04	3.9E+04	1.6E+04	2.0E+04	2.9E+04	2.5E+04	1.3E+05	3.0E+04
2,4-D	soil	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.1E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.0E+01	3.3E+01
Antimony	soil	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.1E-03	1.9E-03	2.0E-03	2.0E-03
Arsenic	soil	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	4.6E+04	5.2E+03	3.0E+04	5.2E+03
Atrazine	soil	-1.0E-02	-9.3E-03	-1.0E-02	-1.2E-02	-1.3E-02	-1.1E-02	-1.1E-02	-1.2E-02	-1.6E-02	-1.7E-02	-1.5E-02	-1.3E-02
Barium	soil	-2.5E+03	-3.7E+03	-4.8E+03	-4.4E+03	-1.1E+03	-4.6E+03	-4.2E+03	-5.3E+03	-4.1E+03	-2.9E+03	-4.9E+03	-4.2E+03
Bentazone	soil	1.0E+00	1.1E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Cadmium	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	2.0E+04	1.3E+03	1.3E+04	1.3E+03
Chlorothalonil	soil	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01
Chromium	soil	5.4E+02	5.3E+02	5.3E+02	5.3E+02	5.4E+02	5.3E+02	5.3E+02	5.3E+02	5.0E+03	5.4E+02	3.2E+03	5.3E+02
Chromium VI	soil	-9.1E+02	-9.3E+02	-1.4E+03	-1.2E+03	-1.6E+03	-1.3E+03	-1.2E+03	-1.5E+03	-1.2E+03	-9.2E+02	-1.3E+03	-1.3E+03
Cobalt	soil	-4.1E+01	-3.9E+01	-3.6E+01	-3.2E+01	-4.0E+01	-3.7E+01	-3.9E+01	-3.4E+01	-3.4E+01	-3.9E+01	-4.5E+01	-3.6E+01
Copper	soil	-1.9E+05	-1.9E+05	-2.0E+05	-1.9E+05	-2.0E+05	-2.0E+05	-1.9E+05	-2.0E+05	1.3E+06	-1.9E+05	7.2E+05	-2.0E+05
Cypermethrin	soil	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.4E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.3E+05	1.1E+05
Dinoseb	soil	-4.7E+00	-4.8E+00	-1.2E+01	-6.4E+00	-6.2E+00	-6.0E+00	-6.2E+00	-6.4E+00	-7.4E+00	-5.8E+00	-1.1E+01	-5.1E+00
Glyphosate	soil	1.8E+01	1.7E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01
Lead	soil	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.2E+04	3.7E+03	2.1E+04	3.7E+03
Linuron	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03
Mercury	soil	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	6.8E+03	7.2E+02	4.4E+03	7.2E+02
Metazachlor	soil	1.0E+01	5.7E+00	1.0E+01	1.0E+01	9.9E+00	1.0E+01	1.0E+01	1.0E+01	9.4E+00	1.0E+01	9.5E+00	1.0E+01
Metolachlor	soil	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.2E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.1E+04	2.6E+04
Molybdenum	soil	-1.3E+00	-1.2E+00	-1.2E+00	-1.1E+00	-1.3E+00	-1.2E+00	-1.3E+00	-1.1E+00	-1.1E+00	-1.4E+00	-1.5E+00	-1.2E+00
Nickel	soil	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.1E+06	1.3E+05	7.4E+05	1.3E+05
Pirimicarb	soil	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.5E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.4E+01	2.0E+01
Selenium	soil	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04
Thallium	soil	5.8E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.7E-05	5.8E-05
Tin	soil	-9.1E-04	2.0E-03	-9.3E-04	-3.7E-03	-5.0E-03	-4.2E-03	-3.6E-03	-5.8E-03	-3.5E-03	-2.5E-02	-2.8E-03	-1.2E-02
Vanadium	soil	-2.4E+02	-2.3E+02	-2.1E+02	-1.9E+02	-2.3E+02	-2.2E+02	-2.3E+02	-2.0E+02	-2.0E+02	-2.1E+02	-2.7E+02	-2.1E+02
Zinc	soil	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	5.1E+05	4.5E+04	3.3E+05	4.5E+04

Appendix C: Pollutant emissions limits

Table 31: Pollutant emissions limits for the WID and LCPD (Faria, 2010)

Daily average limit	EU Waste Incinerator Directive µg/m³	Eu Large Combustion Plant Directive µg/m³
Dust	10	50 – 100, depending on plant size
Sulphur Dioxide (SO_2)	50	200 - 850
NOx	200	500 - 600

Appendix D: Summary of SRF data (Lochab, 2009)

Table 32: Summary of SRF plants currently operating in the UK

SRF Producer	Process notes	Location	SRF Produced (t/yr)	Calorific Value (MJ/kg)	Facility/Industry Utilising the SRF	Power Generated	
Shanks/Eco-deco[1]	Intelligent Transfer[1] Station Bio-drying MBT	Frog Island, East London[2]	75000[2]	17[2]	Hanson[2] & CEMEX[15]	28.3	MWth[3]
Shanks/Eco-deco[1]	Intelligent Transfer[1] Station Bio-drying MBT	Jenkins Lane, East London[2]	75000[2]	17[2]	Hanson[2]	28.3	MWth[3]
Shanks/Eco-deco[1]	Intelligent Transfer[1] Station Bio-drying MBT	Locharmoss, Dumfries and Galloway[2]	10000[4]	17[2]	Lafarge[2]	3.8	MWth[3]
			15000[5]	17[2]	Scotgen Gasification plant [5]	2.0	MWe[5]
Biffa[6]	MBT (Ball Mill) [6]	Leicester[6]	35000[8]	16.5[7]	Hanson[8]	12.8	MWth[3]
Biffa/Island Waste[9]	MBT like process[10]	Forest Rd., Isle of Wight[10]	30000[9]	12.5[9]	Energos gasification plant[9]	1.8	MWe[11]
Slough Heat and Power/Scottish and Southern Energy[12]	MBT like process[13]	Slough[12]	80000[12]	18[12]	Slough Heat and power CHP/Scottish and Southern Energy[12]	11.0	MWe[12]
Materials Recovery and Energy Centre[14]	MBT like process[14]	Neath Port Talbot[14]	30000[15]	16.5[7]	CEMEX[15]	11.0	MWth[3]
Orchid Environmental[16]	Continuous heat treatment MHT[17]	Huyton, Merseyside[16]	20000[18]	15[19]	CEMEX[15]	6.7	MWth[3]
Yorwaste/Wastec[20]	MBT like process[21]	Seamer Carr, Scarborough[22]	18000[22]	15[22]	Scarborough Power/GEM pyrolysis[22]	2.4	MWe[22]
						1.8	MWth[22]
~ 30 companies[15]		Various[15]	62000[15]	20[15]	CEMEX[15]	27.6	MWth[3]
Total			**450000**			**17.2**	**MWe**
						120.3	**MWth**

[1]Archer et al., 2005
[2]Welsby, 2009, personal communication
[3] Estimate with cement kiln efficiency 60% (Roberts & Spencer, 2009, personal communication) and 7500 operational hours annually
[4] calculated as 25000-15000=total SRF produced-amount sent to Scotgen (Welsby, 2009; Brotherton, 2009, personal communications)
[5] Brotherton, 2009, personal communication
[6] www.biffaleicester.co.uk/about/bursom.php [accessed 08/09]
[7] Estimated average calorific value using 15-18MJ/kg (Garg et al., 2007)
[8]Arias-Garcia and Gleeson, 2009a,b,c,d,e

[9] Clarke, 2009, personal communication
[10] www.islandwaste.co.uk/w2e.html [accessed 08/09]
[11] www.defra.gov.uk/environment/waste/wip/newtech/dem-programme/pdf/Energos.pdf [accessed 08/09]
[12] Watson, 2009, personal communication
[13] www.fibrefuel.co.uk/About%20Us.htm [accessed 08/09]
[14] www.neath-porttalbot.gov.uk/default.aspx?page=2554 [accessed 08/09]
[15] Roberts & Spencer, 2009, personal communication
[16] www.defra.gov.uk /environment/waste/wip/newtech/dem-programme/pdf/MWDA.pdf [accessed 08/09]
[17] Defra, 2007a
[18] Estimate based on assumption that 40% of incoming waste converted to SRF ([16])
[19] Estimated average using range 14-16MJ/kg (Juniper Consultancy Services, 2007)
[20] Sharkey, 2009, personal communication
[21] www.wastec.co.uk/system/seamer.html [accessed 08/09]
[22] www.defra.gov.uk/envrionment/waste/wip/newtech/dem-programme/pdf.Scarborough-Power.pdf [accessed 08/09]

Table 33: Summary of planned SRF plants in the UK that will be operational in the near future

SRF Producer	Process Notes	Location	SRF Produced (t/yr)	Calorific Value (MJ/kg)	Status	Facility/Industry that will utilise the SRF	Potential Power Generated	
Hills Group/Entsorga[1]	High Efficiency Biological Treatment - Biodrying MBT[1]	Westbury[1]	30000[2]	16.5[3]	2011[1]	TBC[1]	3.7	MWe[4]
Shanks/Eco-deco[5]	Intelligent Transfer Station Bio-drying MBT[5]	Hespin Wood, Cumbria[6]	40000[6]	13.5[6]	Summer 2011[6]	TBC multi-fuel power station[6]	4.0	MWe[7]
Shanks/Eco-deco[5]	Intelligent Transfer Station Bio-drying MBT[5]	Barrow-in-Furness, Cumbria[6]	40000[6]	13.5[6]	Early 2012[6]	TBC multi-fuel power station[6]	4.0	MWe[7]
CEMEX[8]	MBT[8]	Rugby[8]	150000[8]	20[8]	2011[8]	CEMEX Rugby[8]	66.7	MWth[9]
Mersey Green Solution[10]	MBT like process[10]	Hooton Park[10]	150000[12]	14-16[10]	2012[11]	Hooton Park gasification plant[11]	40.0	MWe[11]
Mersey Green Solution[10]	Composting MBT[10]	Widness Waterfront[10]	150000[11]	14-16[10]	2011[11]	Hooton Park gasification plant[11]	" "	
Biffa[13]	Anaerobic digestion MBT[13]	Brookhurst Wood, West Sussex[13]	130000[13]	11.5[14]	Summer 2011[13]	TBC gasification at Brookhurst Wood if other outputs not found[13]	3.7	MWe[15]
Veolia[16]	MBT[16]	Old Kent Road, Southwark[16]	60000[16]	16.5[3]	2011[16]	South East London CHP[16]	7.4	MWe[4]
Resource Recovery Solutions/Entsorga[17]	High Efficiency Biological Treatment - Biodrying MBT[17]	Sinfin Lane, Derby[17]	130000[18]	11 to 12[18]	Oct-2011[17]	Energos gasification, Sinfin Ln Derby[17]	4.0	MWe[19]
Graphite Resources[20]	Autoclave MHT[20]	Derwenthaugh EcoParc[20]	105000[21]	16.3[21]	Autumn 2009[20]	TBC[21]	12.8	MWe[22]
Graphite Resources[20]	Autoclave MHT[20]	South Tees EcoParc, Tees Valley[20]	105000[21]	16.3[21]	Construction starting 2009[20]	TBC[21]	12.8	MWe[22]
Viridor/Laing[23]	Anaerobic digestion MBT[23]	Arkwright St, Oldham[23]	-		Spring 2010[23]		-	
Viridor/Laing[23]	Anaerobic digestion MBT[23]	Reliance St, Newton Heath[23]	-		Summer 2009[23]		-	
Viridor/Laing[23]	Anaerobic digestion MBT[23]	Cobden St, Salford[23]	275000[24]	11.5[24]	Early 2011[23]			
Viridor/Laing[23]	Anaerobic digestion MBT[23]	Longley Lane, Manchester[23]	-		Spring 2010[23]	Ineos Chlor CHP plant, Runcorn[24]	34.7	MWe[24]

							174	MWth[24]
Viridor/Laing[23]	Anaerobic digestion MBT[23]	Bredbury Park Industrial Estate, Stockport[23]	-		Spring 2010[23]		-	
Viridor[25]	MBT	Lostock Gralam, Northwich[25]	100000[25]	11.5[24]	2012 [25]		-	
Orchid Environmental[26]	Continuous heat treatment (MHT)[27]	Shotton, Flintshire[26]	68000[26]	15[28]	TBC	TBC	7.6	MWe[29]
Peel Environmental[30]	MBT[30]	Ince, Cheshire[30]	50000[31]	16.5[3]	TBC	Ince Resource Recovery Park CHP[30]	7.9	MWe[32]
Total			**1583000**				**142.8**	**MWe**
							240.7	**MWth**

[1] www.hills-group.co.uk/westbury.php [accessed 08/09]
[2] Arias-Garcia & Gleeson, 2009a,b,c,d,e
[3] Estimated average using range 15-18MJ/kg (Garg et al., 2007)
[4] Estimate using methodology from Lee et al. (2005) assuming SRF produces 928 kWh/t
[5] Archer et al., 2005
[6] Welsby, 2009, personal communication
[7] Estimate from method of Lee et al. (2005) assuming SRF produces 759 kWh/t
[8] Roberts & Spencer, 2009, personal communication
[9] Estimate cement kiln efficiency 60%, 7500 operational hours (Roberts & Spencer, 2009, personal communication)
[10] Baker, 2009, personal communication
[11] Riley, 2009, personal communication
[12] best estimate from Baker (2009, personal communication)
[13] www.biffa.co.uk/content/other_areas/west_sussex [accessed 08/09]
[14] Estimated from calorific value of other AD MBTs by Viridor Laing
[15] Estimated from electrical yield produced at similar gasification plant in Sinfin Lane
[16] www.veoliaenvironmentalservices.co.uk/london/pages/southwark_waste.asp [accessed 08/09]
[17] www.rrsderbyshire.com/SitesSinfinLaneDerby.html [accessed 08/09]
[18] Whitmore, 2009, personal communication
[19] Estimate based on plant exporting 30,000MWhe per year, and operational for 7500 hours (Whitmore, 2009, personal communication)
[20] www.graphiteresources.com/locations.aspx [accessed 08/09]
[21] Gray, 2009, personal communication
[22] Estimated using method of Lee et al. (2005) assuming SRF produces 916 kWh/t
[23] www.manchester-consultation.co.uk/index.php [accessed 08/09]
[24] Keppel Seghers, 2009
[25] www.viridor-consultation.co.uk/index.php?contentId=141 [accessed 08/09]
[26] http://news.bbc.co.uk/1/hi/wales/north_east/8138028.stm [accessed 08/09]
[27] Defra, 2007a
[28] Estimated average using range of 14-16MJ/kg (Juniper Consultancy Services, 2007)
[29] Estimated from methodology of Lee et al. (2005) assuming SRF produces 843 kWh/t
[30] www.incerrp.co.uk/index2.html [accessed 09/09]
[31] Estimate based on assumption that 50% of incoming waste is converted to SRF (Letsrecycle.com)
[32] Estimate based on assumption Ince plant produces 95MWe form 600,000tpa SRF [(30)]

Appendix E: Emissions by pollutant, varied electricity mix

Table 34: Norway GHG emissions by pollutant (kg CO_2 equivalent)

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-7.6E+06	-1.8E+07	-2.7E+07	-2.7E+07	-3.4E+07	-4.0E+07	-4.8E+07	-5.8E+07	-3.9E+07	-3.4E+07	-6.1E+07	-2.3E+07
Carbon dioxide (CO_2)	4.9E+04	4.9E+04	4.9E+04	5.3E+04	6.0E+04	4.9E+04	4.9E+04	4.9E+04	4.9E+04	4.8E+04	6.0E+04	4.9E+04
Carbon dioxide, fossil	-3.0E+07	-1.3E+07	-3.9E+07	-4.5E+07	-4.6E+07	-3.4E+07	-3.4E+07	-3.9E+07	-2.7E+07	-2.8E+07	-5.0E+07	-3.7E+07
Carbon Monoxide (CO)	5.3E+04	-1.7E+03	4.1E+04	5.3E+04	3.4E+04	6.5E+03	1.2E+04	5.1E+02	-3.1E+02	2.0E+04	5.4E+03	3.7E+04
Carbon monoxide, biogenic	-3.0E+05	-3.0E+05	-4.9E+05	-4.3E+05	-5.5E+05	-4.4E+05	-4.1E+05	-5.1E+05	-4.2E+05	-3.0E+05	-4.4E+05	-4.4E+05
Carbon monoxide, fossil	-1.3E+05	-1.6E+05	-1.9E+05	-2.3E+05	-2.4E+05	-1.9E+05	-1.8E+05	-2.0E+05	-1.9E+05	-1.5E+05	-2.2E+05	-1.8E+05
Carbon tetrachloride [Tetrachloromethane]	2.5E+02	6.0E+01	5.7E+02	2.2E+02	1.5E+02	9.6E+01	2.9E+01	1.2E+01	2.2E+01	-5.3E+02	7.4E+00	-8.2E+00
Chlorinated Matter (unspecified, as Cl)	-8.2E-05	1.4E-07	-3.9E-05	-9.7E-05	-7.9E-05	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-4.9E-04	-9.9E-05	-2.3E-04
Dichloromethane	1.2E+00	-7.5E-01	3.6E-01	8.1E-01	4.0E-01	8.9E-02	-4.1E-01	-5.3E-01	-4.6E-01	-1.3E-01	-5.6E-01	8.0E-01
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-3.4E+01	-3.5E+01	-2.1E+01	-3.7E+01	-4.7E+01	-3.7E+01	-3.5E+01	-3.9E+01	-4.4E+01	-3.3E+01	-3.7E+01	-3.9E+01
Ethane, 1,1,1-trichloro-, HCFC-140	1.6E+03	2.6E+01	4.3E+02	1.2E+03	5.7E+02	8.2E+02	4.5E+02	7.3E+02	7.6E+02	4.8E+02	1.5E+02	1.1E+03
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2.6E+04	4.4E+02	6.3E+03	1.9E+04	1.0E+04	1.2E+04	7.1E+03	1.1E+04	1.2E+04	7.8E+03	2.6E+03	1.7E+04
Ethane, 1,1-difluoro-, HFC-152a	-7.4E-01	-7.7E-01	-8.1E-01	-7.8E-01	-9.4E-01	-8.5E-01	-8.6E-01	-8.9E-01	-8.1E-01	-9.4E-01	-9.3E-01	-8.4E-01
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	3.0E+04	-1.8E+03	5.0E+03	2.1E+04	9.3E+03	1.3E+04	6.1E+03	1.0E+04	1.2E+04	7.3E+03	1.5E+02	1.8E+04
Ethane, 1-chloro-1,1-difluoro-, HCFC-142	2.1E+03	3.5E+01	5.9E+02	1.6E+03	7.8E+02	1.1E+03	6.2E+02	9.8E+02	1.0E+03	6.5E+02	2.0E+02	1.5E+03
Ethane, 2,2-dichloro-1,1,1-tri-fluoro-, HCFC-123	2.2E+01	3.7E-01	5.4E+00	1.6E+01	8.6E+00	1.1E+01	6.0E+00	9.0E+00	9.8E+00	6.7E+00	2.2E+00	1.4E+01
Ethane, 2-chloro-1,1,1,2-tetra-fluoro-, HCFC-124	8.3E+01	1.3E+00	2.3E+01	6.3E+01	3.0E+01	4.3E+01	2.4E+01	3.8E+01	4.0E+01	2.5E+01	7.8E+00	5.8E+01
Hydrocarbons (unspecified)	-1.0E+02	1.7E+03	-9.9E+01	-1.3E+02	-1.5E+02	-1.2E+02	-1.1E+02	-1.2E+02	-2.0E+02	-1.0E+02	-1.9E+02	-1.1E+02
Methane, (unspecified)	2.9E+07	5.4E+05	2.4E+07	2.7E+07	2.1E+07	1.1E+07	3.7E+06	1.5E+06	1.2E+06	9.8E+06	3.7E+06	2.4E+07
Methane, biogenic	9.5E+03	9.4E+03	3.4E+04	2.7E+04	4.0E+04	7.1E+04	4.5E+04	4.5E+04	8.6E+03	4.1E+04	4.4E+04	4.3E+04
Methane, bromochlorodifluoro-, Halon 1211	9.9E+01	-2.5E+02	7.4E+01	8.5E+01	1.8E+03	7.8E+01	7.9E+01	8.6E+01	3.5E+02	3.6E+01	8.9E+01	6.5E+01
Methane, bromotrifluoro-, Halon 1301	-4.9E+02	-4.4E+02	-8.7E+02	-7.9E+02	-1.1E+03	-8.5E+02	-7.9E+02	-9.9E+02	-9.0E+02	-5.6E+02	-9.1E+02	-7.7E+02
Methane, chlorodifluoro-, HCFC-22	3.0E+03	-7.0E+02	8.9E+02	2.3E+03	6.9E+03	1.6E+03	9.4E+02	1.4E+03	2.4E+03	8.2E+02	4.0E+02	2.1E+03
Methane, chlorotrifluoro-, CFC-13	1.1E+04	1.9E+02	2.8E+03	8.4E+03	4.5E+03	5.5E+03	3.1E+03	4.7E+03	5.1E+03	3.5E+03	1.1E+03	7.5E+03

Methane, dichlorodifluoro-, CFC-12	6.7E+04	1.1E+03	1.9E+04	5.1E+04	2.5E+04	3.5E+04	1.9E+04	3.1E+04	3.3E+04	2.0E+04	6.4E+03	4.7E+04
Methane, fossil	-2.3E+06	-2.8E+06	-5.8E+06	-4.0E+06	-1.1E+06	-1.0E+07	-1.3E+07	-1.4E+07	-6.9E+06	-1.0E+07	-8.3E+06	-4.1E+06
Methane, tetrafluoro-, FC-14	-3.8E+06	-3.8E+06	-6.3E+06	-5.5E+06	-7.1E+06	-5.6E+06	-5.3E+06	-6.6E+06	-5.4E+06	-3.8E+06	-5.6E+06	-5.6E+06
Methane, trichlorofluoro-, CFC-11	1.5E+03	2.6E+01	3.7E+02	1.1E+03	5.9E+02	7.2E+02	4.1E+02	6.2E+02	6.7E+02	4.6E+02	1.5E+02	9.9E+02
Methane, trifluoro-, HFC-23	-1.2E+00	-4.0E-01	-7.9E-01	-1.3E+00	-1.2E+00	-1.5E+00	-1.4E+00	-1.6E+00	-1.5E+00	-5.1E+00	-1.4E+00	-2.6E+00
Methyl bromide [Bromomethane]	3.1E-08	3.1E-08	4.9E-08	4.3E-08	5.6E-08	4.4E-08	4.2E-08	5.1E-08	4.2E-08	3.0E-08	4.5E-08	4.4E-08
Methyl chloride [Chloromethane]	3.0E+00	1.7E-01	1.8E+00	2.5E+00	1.9E+00	1.4E+00	6.6E-01	4.8E-01	5.8E-01	1.1E+00	4.4E-01	2.5E+00
Nitrous oxide	-1.3E+05	2.0E+06	-4.3E+04	-6.8E+03	-7.0E+04	2.8E+05	9.3E+04	7.2E+04	6.4E+04	-8.8E+05	4.8E+04	-2.3E+05
Sulphur hexafluoride	-5.0E+04	-5.1E+04	-5.4E+04	-5.2E+04	-6.4E+04	-5.3E+04	-5.3E+04	-5.5E+04	-5.3E+04	-5.5E+04	-6.1E+04	-5.4E+04

Table 35: Norway abiotic resource depletion impacts by pollutant

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-2.9E+05	-3.6E+05	-5.7E+05	-4.8E+05	-1.2E+05	-8.4E+05	-9.8E+05	-1.1E+06	-5.9E+05	-8.0E+05	-7.5E+05	-4.4E+05
Aluminium, 24% in bauxite, 11% in crude ore, in ground	-2.4E-02	-2.4E-02	-4.0E-02	-3.4E-02	-4.4E-02	-3.5E-02	-3.3E-02	-4.1E-02	-3.4E-02	-2.4E-02	-3.6E-02	-3.5E-02
Anhydrite, in ground	-1.6E-03	-1.6E-03	-1.6E-03	-3.5E-03	-1.9E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-2.9E-03	-1.6E-03
Barite, 15% in crude ore, in ground	-3.6E-01	-5.6E-01	-7.1E-01	-6.4E-01	5.6E-02	-7.0E-01	-6.5E-01	-8.2E-01	-6.0E-01	-5.0E-01	-7.6E-01	-6.4E-01
Borax, in ground	1.6E-03	1.7E-01	1.3E-01	5.3E-03	1.8E-03	1.6E-03	1.6E-03	1.6E-03	1.5E-03	1.6E-03	1.6E-02	1.6E-03
Calcite, in ground	-2.4E-04	2.2E-04	-3.9E-04	-3.7E-04	-4.7E-04	-3.4E-04	-3.2E-04	-3.6E-04	-3.4E-04	-3.5E-04	-3.3E-04	-3.1E-04
Cerium, in ground	7.2E-18	7.1E-18	1.2E-17	1.0E-17	1.4E-17	1.1E-17	1.0E-17	1.2E-17	1.0E-17	7.5E-18	1.1E-17	1.1E-17
Chromium, 25.5 in chromite, 11.6% in crude ore, in ground	5.9E-02	8.6E-01	2.6E-01	4.4E-01	6.4E-01	3.2E-01	4.7E-01	5.1E-01	2.9E-01	-4.5E-01	2.9E-01	-1.7E-01
Chrysotile, in ground	-3.3E-09	-1.7E-09	-7.0E-09	-5.8E-09	-7.2E-09	-6.1E-09	-5.6E-09	-7.4E-09	-5.7E-09	-1.3E-08	-5.2E-09	-9.3E-09
Cinnabar, in ground	-1.4E-01	-7.0E-02	-8.7E-02	-2.2E-01	-2.8E-01	-2.4E-01	-2.2E-01	-3.0E-01	-2.3E-01	-5.2E-01	-2.1E-01	-3.7E-01
Coal (in ground)	-9.5E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03
Coal, brown, in ground	-3.3E+04	-3.4E+04	-4.3E+04	-3.9E+04	-4.9E+04	-4.2E+04	-4.1E+04	-4.6E+04	-4.0E+04	-3.8E+04	-4.4E+04	-4.1E+04
Coal, hard, unspecified, in ground	-1.2E+05	-1.3E+05	-3.5E+05	-1.6E+05	-2.1E+05	-6.2E+05	-7.7E+05	-8.3E+05	-4.3E+05	-6.1E+05	-4.5E+05	-2.4E+05
Cobalt, in ground	1.1E-07	2.6E-09	-2.5E-07	-2.7E-07	-5.2E-07	-3.0E-07	-2.3E-07	-5.6E-07	-5.4E-07	2.5E-08	-5.2E-07	-2.1E-07
Colemanite, in ground	5.6E-02	5.7E-02	5.3E-02	5.4E-02	5.1E-02	5.4E-02	5.4E-02	5.2E-02	5.8E-02	5.5E-02	5.4E-02	5.3E-02
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	-1.5E+00	-1.5E+00	-2.2E+00	-2.0E+00	-2.5E+00	-2.1E+00	-2.0E+00	-2.4E+00	-2.0E+00	-1.8E+00	-2.1E+00	-2.1E+00

Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	-8.2E+00	-8.1E+00	-1.2E+01	-1.1E+01	-1.4E+01	-1.2E+01	-1.1E+01	-1.3E+01	-1.1E+01	-9.9E+00	-1.2E+01	-1.2E+01
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	-2.2E+00	-2.1E+00	-3.3E+00	-2.9E+00	-3.7E+00	-3.0E+00	-2.9E+00	-3.5E+00	-2.9E+00	-2.6E+00	-3.1E+00	-3.2E+00
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	-1.1E+01	-1.1E+01	-1.6E+01	-1.5E+01	-1.7E+01	-1.5E+01	-1.4E+01	-1.7E+01	-1.5E+01	-1.3E+01	-1.5E+01	-1.6E+01
Dolomite, in ground	7.9E-08	1.0E-07	8.2E-08	9.3E-08	1.4E-07	7.8E-08	8.2E-08	9.0E-08	7.8E-08	7.6E-08	1.0E-07	7.8E-08
Fluorine, 4.5% in apatite, 1% in crude ore, in ground	1.4E-04	4.6E-04	1.2E-04	1.8E-04	1.5E-04	1.2E-04	1.2E-04	1.2E-04	1.2E-04	-2.6E-02	1.6E-04	-8.4E-03
Fluorine, 4.5% in apatite, 3% in crude ore, in ground	-4.5E-03	-4.3E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.1E-03	-4.5E-03	-1.6E-02	-4.5E-03	-8.2E-03
Fluorspar, 92%, in ground	-3.9E-03	-1.6E-03	-6.3E-03	-5.1E-03	-6.8E-03	-5.7E-03	-5.3E-03	-6.6E-03	-5.4E-03	-1.8E-01	-5.5E-03	-6.4E-02
Gas, mine, off-gas, process, coal mining	-1.8E+03	-1.9E+03	-6.5E+03	-2.3E+03	-2.9E+03	-1.3E+04	-1.6E+04	-1.7E+04	-8.5E+03	-1.3E+04	-8.8E+03	-4.1E+03
Gas, natural, in ground	-3.3E+04	-9.9E+04	-4.2E+04	-8.7E+04	2.9E+05	-3.9E+04	-3.8E+04	-3.8E+04	1.3E+04	-4.6E+04	-7.2E+04	-4.1E+04
Gypsum, in ground	3.1E-03	3.1E-03	4.7E-03	2.1E-02	5.3E-03	4.2E-03	4.0E-03	4.8E-03	4.0E-03	3.1E-03	4.7E-03	4.2E-03
Iron, 46% in ore, 25% in crude ore, in ground	-2.3E-01	-2.9E-01	-3.5E-01	-3.3E-01	-4.7E-01	-3.3E-01	-3.1E-01	-3.5E-01	-3.2E-01	-2.5E-01	-3.3E-01	-3.3E-01
Kaolinite, 24% in crude ore, in ground	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.5E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.4E-03	-2.0E-03
Kieserite, 25% in crude ore, in ground	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01
Lanthanum, in crude ore, in ground	4.7E-18	4.7E-18	7.6E-18	6.6E-18	8.6E-18	6.8E-18	6.4E-18	7.9E-18	6.5E-18	4.3E-18	6.8E-18	6.7E-18
Lead (Pb, ore)	-4.1E+01	-4.2E+01	-4.5E+01	-4.9E+01	-5.8E+01	-4.7E+01	-4.6E+01	-5.0E+01	-6.3E+01	-4.1E+01	-6.2E+01	-4.7E+01
Magnesite, 60% in crude ore, in ground	-2.2E-07	6.4E-07	-2.3E-07	3.5E-07	1.4E-06	-3.2E-07	-1.7E-07	1.6E-07	-3.4E-07	-3.6E-07	1.3E-07	-2.4E-07
Magnesium, 0.13% in water	-5.9E-09	-5.9E-09	-6.0E-09	-5.9E-09	-6.5E-09	-6.1E-09	-6.2E-09	-6.3E-09	-6.0E-09	-6.2E-09	-7.1E-09	-5.9E-09
Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	1.2E-02	2.7E-02	2.0E-02	2.7E-02	2.8E-02	2.0E-02	2.2E-02	3.1E-02	1.6E-02	2.8E-02	2.6E-02	2.2E-02
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude	-3.3E+00	-3.2E+00	-4.9E+00	-4.4E+00	-5.2E+00	-4.6E+00	-4.3E+00	-5.2E+00	-4.4E+00	-4.0E+00	-4.6E+00	-4.7E+00

ore, in ground												
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	-4.7E-01	-4.6E-01	-7.0E-01	-6.3E-01	-7.9E-01	-6.5E-01	-6.2E-01	-7.5E-01	-6.2E-01	-5.6E-01	-6.6E-01	-6.7E-01
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	9.7E+00	2.2E+01	1.6E+01	2.2E+01	2.2E+01	1.6E+01	1.8E+01	2.5E+01	1.3E+01	2.3E+01	2.1E+01	1.7E+01
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	-1.7E+00	-1.7E+00	-2.6E+00	-2.3E+00	-2.9E+00	-2.4E+00	-2.3E+00	-2.7E+00	-2.3E+00	-2.1E+00	-2.4E+00	-2.5E+00
Molybdenum, 0.11% in sulfide, Mo 0.41% and Cu 0.36% in crude ore, in ground	2.0E+01	4.3E+01	3.2E+01	4.5E+01	4.5E+01	3.3E+01	3.6E+01	5.1E+01	2.6E+01	4.6E+01	4.3E+01	3.5E+01
Neodymium, in ground	1.1E-26	1.1E-26	1.8E-26	1.6E-26	2.1E-26	1.7E-26	1.6E-26	1.9E-26	1.6E-26	1.2E-26	1.7E-26	1.7E-26
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	-1.9E-03	4.9E-03	-2.1E-03	-2.0E-03	-2.3E-03	-2.1E-03	-2.1E-03	-2.2E-03	-2.1E-03	-1.5E-02	-2.2E-03	-6.2E-03
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	1.4E-01	5.9E-01	3.1E-01	4.8E-01	6.1E-01	3.2E-01	3.9E-01	5.3E-01	2.6E-01	1.8E-01	4.0E-01	2.0E-01
Oil, crude, in ground	-8.7E+04	-8.6E+04	-1.2E+05	-1.7E+05	-1.4E+05	-1.1E+05	-1.1E+05	-1.3E+05	-1.2E+05	-9.2E+04	-1.6E+05	-1.1E+05
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-8.1E-04	-7.3E-04	-1.2E-03	-1.2E-03	-1.6E-03	-1.3E-03	-1.3E-03	-1.5E-03	-1.4E-03	-1.5E-03	-1.4E-03	-1.4E-03
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-1.9E-03	-1.8E-03	-3.0E-03	-3.0E-03	-3.7E-03	-3.2E-03	-3.0E-03	-3.7E-03	-3.4E-03	-3.7E-03	-3.5E-03	-3.4E-03
Phosphorus, 18% in apatite, 12% in crude ore, in ground	-5.1E-01	-4.9E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-4.7E-01	-5.1E-01	-1.8E+00	-5.1E-01	-9.4E-01
Phosphorus, 18% in apatite, 4% in crude ore, in ground	1.6E-02	5.2E-02	1.4E-02	2.0E-02	1.7E-02	1.4E-02	1.4E-02	1.3E-02	1.4E-02	-2.9E+00	1.8E-02	-9.6E-01
Pt, Pt 2.5E-4%, Pd	-3.7E-04	-3.8E-04	-4.3E-04	-4.2E-04	-5.1E-04	-4.4E-04	-4.3E-04	-4.6E-04	-4.4E-04	-4.3E-04	-4.9E-04	-4.3E-04

7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground												
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-1.3E-03	-1.4E-03	-1.5E-03	-1.5E-03	-1.8E-03	-1.6E-03	-1.6E-03	-1.7E-03	-1.6E-03	-1.6E-03	-1.8E-03	-1.5E-03
Pyrite, in ground	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.3E-05	9.4E-05	9.3E-05	9.4E-05
Raw Materials (unspecified)	2.8E-17	3.6E-17	2.0E-17	5.1E-17	2.2E-17	1.9E-17	2.0E-17	1.5E-17	2.1E-17	2.0E-17	3.7E-17	2.8E-17
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-2.1E-03	-2.2E-03	-3.3E-03	-3.1E-03	-4.0E-03	-3.3E-03	-3.2E-03	-3.8E-03	-3.5E-03	-2.6E-03	-3.6E-03	-3.1E-03
Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-6.7E-03	-7.1E-03	-1.0E-02	-9.7E-03	-1.3E-02	-1.1E-02	-1.0E-02	-1.2E-02	-1.1E-02	-8.1E-03	-1.2E-02	-9.6E-03
Rhenium, in crude ore, in ground	-6.9E-05	-7.1E-05	-1.1E-04	-9.9E-05	-1.2E-04	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-8.7E-05	-1.2E-04	-9.9E-05
Silver, 0.01% in crude ore, in ground	-1.8E-01	-1.9E-02	-9.8E-02	-2.2E-01	-1.9E-01	-2.4E-01	-2.3E-01	-2.6E-01	-2.4E-01	-1.0E+00	-2.2E-01	-4.9E-01
Sodium chloride, in ground	-3.4E-03	-9.9E-04	-3.4E-03	-5.6E-03	-6.8E-03	-6.0E-03	-5.5E-03	-7.2E-03	-5.6E-03	-2.2E-02	-5.1E-03	-1.2E-02
sodium sulphate, various forms, in ground	-8.5E-03	6.6E-02	-9.8E-03	2.1E-03	-4.8E-04	-1.0E-02	-1.0E-02	-1.1E-02	-9.8E-03	-5.9E+00	-3.2E-03	-2.0E+00
Stibnite, in ground	-6.3E-05	-6.5E-05	-8.6E-05	-7.9E-05	-9.7E-05	-8.3E-05	-8.1E-05	-9.2E-05	-9.0E-05	-7.4E-05	-9.3E-05	-8.2E-05
Sulfur, in ground	-2.2E-01	-2.2E-01	-2.2E-01	-3.1E-01	-2.5E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.3E-01	-2.9E-01	-2.2E-01
sylvite, 25 % in sylvinite, in ground	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04
Talc, in ground	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.3E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.2E-04	-1.0E-04
Tin, 79% in cassiterite, 0.1% in crude ore, in ground	-9.4E-02	-5.0E-02	-6.5E-02	-1.1E-01	-1.0E-01	-1.2E-01	-1.1E-01	-1.2E-01	-1.2E-01	-3.3E-01	-1.2E-01	-1.8E-01
Ulexite, in ground	-2.9E-03	-2.9E-03	-3.0E-03	-3.0E-03	-3.6E-03	-3.1E-03	-3.1E-03	-3.2E-03	-3.1E-03	-3.4E-03	-3.5E-03	-3.1E-03
Uranium, in ground	-9.0E-01	-9.1E-01	-1.1E+00	-1.1E+00	-1.3E+00	-1.1E+00	-1.1E+00	-1.2E+00	-1.1E+00	-9.8E-01	-1.2E+00	-1.1E+00
Zinc (Zn, ore)	1.6E+02	1.6E+02	2.7E+02	2.3E+02	3.0E+02	2.4E+02	2.2E+02	2.8E+02	2.3E+02	1.6E+02	2.4E+02	2.4E+02
Zirconia, as baddeleyite, in ground	-6.2E-07	-6.9E-09	-3.0E-07	-7.3E-07	-6.1E-07	-8.1E-07	-7.8E-07	-8.9E-07	-8.2E-07	-3.7E-06	-7.5E-07	-1.7E-06

Table 36: Norway acidification impacts by pollutant (kg SO_2 equivalent)

Substances	Landfill	Incinerati	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-184911	-127127	-252044	-252308	-267722	-281274	-273358	-307795	-243560	-233186	-331640	-236949
Ammonia	506	5571	4258	4173	1497	1088	1255	362	5742	3088	6364	5503
Nitrogen oxides (NO and NO_2 as NO_2)	-25163	26782	-17648	-41116	-41510	1027	22261	20504	-10829	19558	-43548	-24842
Sulfur dioxide	-148063	-153121	-205719	-204193	-214704	-195228	-189256	-218289	-186592	-179286	-212341	-196233
Sulphur oxides (SO_2 and SO_3 as SO_2)	-12192	-6359	-32934	-11171	-13004	-88161	-107619	-110372	-51881	-76546	-82116	-21377

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		1.9E+04	5.4E+03	1.4E+04	1.5E+04	2.8E+03	1.4E+03	4.0E+03	-1.7E+03	3.9E+03	1.2E+04	-6.4E+03	7.0E+03
Ammonia	air	1.1E+02	1.2E+03	9.3E+02	9.1E+02	3.3E+02	2.4E+02	2.8E+02	7.9E+01	1.3E+03	6.8E+02	1.4E+03	1.2E+03
Nitrate	air	5.2E-01	5.3E-01	5.0E-01	5.9E-01	6.6E-01	5.5E-01	5.4E-01	5.6E-01	7.9E-01	5.2E-01	7.7E-01	5.5E-01
Nitrogen oxides (NO and NO_2 as NO_2)	air	-6.5E+03	7.0E+03	-4.6E+03	-1.1E+04	-1.1E+04	2.7E+02	5.8E+03	5.3E+03	-2.8E+03	5.1E+03	-1.1E+04	-6.5E+03
Nitrous oxide	air	-1.2E+02	1.8E+03	-3.9E+01	-6.2E+00	-6.4E+01	2.5E+02	8.4E+01	6.5E+01	5.8E+01	-8.0E+02	4.4E+01	-2.1E+02
Phosphorus	air	-5.8E+01	-5.8E+01	-5.6E+01	-5.7E+01	-6.7E+01	-5.7E+01	-5.7E+01	-5.6E+01	-5.6E+01	-5.9E+01	-6.6E+01	-5.6E+01
Ammonia (NH_4^+, NH_3, as N)	water	3.0E+04	8.1E+02	2.6E+04	3.1E+04	2.2E+04	6.8E+03	5.1E+03	1.6E+03	1.7E+03	1.5E+04	3.6E+03	2.1E+04
Ammonium, ion	water	-6.0E+01	-3.8E+01	-7.2E+01	-7.1E+01	-7.0E+01	-7.7E+01	-7.8E+01	-8.3E+01	-7.3E+01	-1.1E+02	-7.1E+01	-8.4E+01
COD, Chemical Oxygen Demand	water	-2.6E+03	-2.7E+03	-3.5E+03	-1.9E+03	-3.7E+03	-3.2E+03	-3.2E+03	-3.7E+03	-3.3E+03	-2.9E+03	-2.5E+03	-3.3E+03
Nitrate	water	8.9E+02	9.0E+02	8.7E+02	8.8E+02	9.4E+02	8.7E+02	8.8E+02	8.6E+02	8.8E+02	8.6E+02	9.4E+02	8.7E+02
Nitrite	water	-2.9E-01	-2.7E-01	-3.5E-01	-3.5E-01	-2.9E-01	-3.6E-01	-3.5E-01	-4.0E-01	-3.5E-01	-5.4E-01	-2.8E-01	-4.4E-01
Nitrogen	water	1.5E+03	1.5E+03	1.4E+03	1.5E+03	1.4E+03	1.5E+03	1.5E+03	1.4E+03	1.3E+04	1.4E+03	8.2E+03	1.4E+03
Nitrogen - as total N	water	8.1E-01	4.5E-01	8.2E-01	7.9E-01	7.7E-01	8.0E-01	8.1E-01	8.0E-01	7.4E-01	8.2E-01	7.5E-01	8.1E-01
Phosphate	water	-3.9E+03	-4.1E+03	-5.9E+03	-5.3E+03	-6.4E+03	-5.6E+03	-5.4E+03	-6.4E+03	-5.4E+03	-6.3E+03	-5.7E+03	-6.2E+03
Phosphorus	water	-8.2E+02	-8.2E+02	-8.2E+02	-8.1E+02	-8.3E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.5E+02	-8.2E+02	-8.3E+02
Phosphorus - as total P	water	-9.7E-07	-9.5E-07	-9.7E-07	-9.7E-07	-9.7E-07	1.3E+03	-9.7E-07	-9.7E-07	-9.6E-07	-9.7E-07	-9.7E-07	-9.7E-07
Nitrogen	soil	2.0E-05	1.3E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05
Phosphorus	soil	-5.0E+01	-5.5E+01	-5.6E+01	-5.6E+01	-5.4E+01	-5.5E+01	-5.4E+01	-5.6E+01	-5.3E+01	-5.1E+01	-6.2E+01	-5.4E+01

Table 37: Human toxicity impacts by pollutant (kg 1,4-DCB equivalents)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		-1.2E+08	-1.2E+08	-1.9E+08	-1.6E+08	-2.1E+08	-1.7E+08	-1.6E+08	-2.0E+08	-1.5E+08	-1.2E+08	-1.6E+08	-1.7E+08
Acenaphthene	air	-2.7E+01	-2.8E+01	-3.7E+01	-3.2E+01	-3.9E+01	-3.3E+01	-3.3E+01	-3.6E+01	-3.2E+01	-3.1E+01	-3.8E+01	-3.3E+01
Acrolein	air	-1.3E+00	-1.2E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00
Ammonia	air	3.2E+01	3.5E+02	2.7E+02	2.6E+02	9.4E+01	6.8E+01	7.9E+01	2.3E+01	3.6E+02	1.9E+02	4.0E+02	3.4E+02
Antimony	air	-2.6E+03	2.3E+04	-2.3E+03	-1.7E+03	-2.4E+03	-1.1E+03	-1.6E+03	-2.9E+03	-9.3E+02	-1.2E+03	-9.6E+02	-1.4E+03
Arsenic	air	-7.6E+05	-2.3E+05	-9.3E+05	-9.2E+05	-1.1E+06	-7.9E+05	-7.9E+05	-8.6E+05	-8.8E+05	-8.7E+05	-8.2E+05	-1.0E+06
Barium	air	-2.7E+03	-2.7E+03	-3.8E+03	-3.3E+03	-4.0E+03	-3.7E+03	-3.7E+03	-4.2E+03	-3.5E+03	-3.3E+03	-3.7E+03	-3.5E+03
Benzene	air	-1.4E+05	-2.0E+05	-1.8E+05	-1.6E+05	-2.1E+05	-1.7E+05	-1.7E+05	-2.0E+05	-1.5E+05	-1.4E+05	-1.7E+05	-1.6E+05
Benzene, ethyl-	air	-4.4E+00	-4.4E+00	-6.3E+00	1.2E+02	-7.6E+00	-6.2E+00	-5.9E+00	-6.9E+00	-6.4E+00	-4.7E+00	-6.8E+00	-5.8E+00
Benzene, pentachloro-	air	5.2E-01	5.1E-01	5.5E-01	5.1E-01	6.4E-01	5.6E-01	5.6E-01	5.8E-01	5.6E-01	5.3E-01	6.2E-01	5.5E-01
Beryllium	air	-3.9E+03	-4.0E+03	-4.8E+03	-4.3E+03	-4.4E+03	-5.2E+03	-5.4E+03	-5.7E+03	-4.9E+03	-5.3E+03	-4.5E+03	-4.5E+03
Butadiene [1,3-Butadiene]	air	1.3E+05	1.2E+05	1.3E+05	1.2E+05	1.1E+05	1.3E+05	1.3E+05	1.3E+05	1.0E+05	1.3E+05	1.1E+05	1.2E+05
Cadmium	air	-1.7E+05	-5.8E+04	-2.3E+05	-2.2E+05	-2.6E+05	-2.0E+05	-1.9E+05	-2.3E+05	-2.0E+05	-2.0E+05	-2.1E+05	-2.3E+05
Carbon disulphide	air	1.4E+02	1.8E+02	2.8E+02	2.5E+02	3.2E+02	2.3E+02	2.3E+02	3.1E+02	1.8E+02	1.5E+02	2.3E+02	2.3E+02
Carbon tetrachloride [Tetrachloromethane]	air	3.9E+01	9.5E+00	8.9E+01	3.4E+01	2.4E+01	1.5E+01	4.6E+00	1.9E+00	3.4E+00	-8.4E+01	1.2E+00	-1.3E+00
Chlorinated Matter (unspecified, as Cl)	air	-4.7E-06	8.3E-09	-2.2E-06	-5.6E-06	-4.6E-06	-6.1E-06	-5.9E-06	-6.8E-06	-6.2E-06	-2.8E-05	-5.7E-06	-1.3E-05
Chloroform [Trichloromethane]	air	2.1E+00	-2.6E-02	1.2E+00	1.7E+00	1.2E+00	8.8E-01	3.3E-01	1.9E-01	2.7E-01	6.2E-01	1.6E-01	1.7E+00
Chromium VI	air	-2.1E+05	6.1E+04	1.1E+06	1.8E+06	2.1E+06	6.2E+05	6.7E+05	9.9E+05	1.7E+06	1.7E+06	1.7E+06	1.5E+06
Cobalt	air	-1.7E+04	8.0E+03	-2.1E+04	-1.8E+04	-2.2E+04	-2.0E+04	-2.0E+04	-2.1E+04	-1.9E+04	-2.1E+04	-1.9E+04	-2.1E+04
Copper	air	-1.7E+05	-1.4E+05	-2.5E+05	-2.2E+05	-2.9E+05	-2.3E+05	-2.1E+05	-2.6E+05	-2.2E+05	-1.7E+05	-2.3E+05	-2.3E+05
Dichloromethane	air	2.7E-01	-1.7E-01	8.1E-02	1.9E-01	9.0E-02	2.0E-02	-9.3E-02	-1.2E-01	-1.1E-01	-2.8E-02	-1.3E-01	1.8E-01
Dioxins and furans- as ITEQ	air	3.2E+01	2.5E+04	2.6E+03	7.2E+01	7.4E+01	8.9E+03	1.1E+04	1.1E+04	4.2E+03	7.5E+03	8.0E+03	1.1E+03
Dioxins and furans- as WHO TEQ	air	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.5E+02	-2.4E+02	-2.4E+02	-2.4E+02
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.4E+05	-2.5E+05	-2.5E+05	-2.5E+05	-3.2E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-3.0E+05	-2.5E+05
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.8E+02	2.9E+00	4.9E+01	1.4E+02	6.5E+01	9.2E+01	5.1E+01	8.2E+01	8.6E+01	5.4E+01	1.7E+01	1.2E+02
Ethane, 1,2-dichloro-	air	-4.3E+01	-4.6E+01	-4.9E+01	-4.6E+01	-5.9E+01	-4.8E+01	-4.8E+01	-4.9E+01	-4.7E+01	-5.0E+01	-5.6E+01	-4.9E+01
Ethylene [Ethene]	air	1.5E+01	5.8E+00	-6.2E+00	-4.0E+00	3.9E+00	-8.4E+00	-8.0E+00	-1.4E+01	-5.5E+00	1.4E+00	1.4E+01	-3.2E+00
Ethylene oxide [1,2-Epoxyethane]	air	-1.6E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04
Formaldehyde [Methanal]	air	-8.5E+01	-9.6E+01	-1.1E+02	-1.0E+02	-1.2E+02	-1.1E+02	-1.0E+02	-1.2E+02	-1.0E+02	-9.3E+01	-1.0E+02	-1.1E+02
Hexachlorobenzene	air	9.7E+02	2.7E+03	1.0E+03	2.1E+03	4.5E+03	8.4E+02	1.1E+03	1.8E+03	8.4E+02	6.3E+02	1.9E+03	7.9E+02
Hydrocarbons (unspecified)	air	-5.6E-01	9.2E+00	-5.4E-01	-6.9E-01	-8.3E-01	-6.2E-01	-6.0E-01	-6.4E-01	-1.1E+00	-5.6E-01	-1.0E+00	-6.2E-01
Hydrogen chloride	air	-8.1E+02	4.3E+02	-7.3E+02	-1.0E+03	7.2E+02	-3.7E+02	-2.8E+02	-3.5E+02	-5.4E+02	-4.0E+02	-8.8E+02	-7.3E+02
Hydrogen fluoride	air	-4.1E+06	-4.5E+06	-6.7E+06	-5.8E+06	-7.5E+06	-6.2E+06	-5.9E+06	-7.3E+06	-6.1E+06	-4.5E+06	-6.4E+06	-6.0E+06
Hydrogen sulfide	air	-1.2E+02	-1.4E+02	-1.2E+02	-1.2E+02	-2.5E+01	-1.2E+02	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02
Lead	air	-2.1E+02	-3.3E+02	2.0E+03	7.5E+02	8.6E+02	1.5E+03	1.4E+03	2.6E+03	9.1E+02	-8.0E+02	1.5E+03	7.0E+02
Mercury	air	-4.9E+03	9.5E+03	-3.2E+03	-3.0E+03	-2.3E+03	-2.6E+03	-2.9E+03	-3.3E+03	-3.0E+03	-9.4E+02	-2.9E+03	-3.9E+03
Methyl bromide [Bromomethane]	air	2.2E-06	2.2E-06	3.5E-06	3.0E-06	3.9E-06	3.1E-06	2.9E-06	3.6E-06	3.0E-06	2.1E-06	3.1E-06	3.1E-06

Molybdenum	air	-1.3E+03	-1.2E+03	-2.0E+03	-1.7E+03	-1.8E+03	-1.9E+03	-1.9E+03	-2.2E+03	-1.8E+03	-2.1E+03	-1.6E+03	-2.0E+03
m-Xylene	air	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.5E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.5E-01	-2.1E-01
Nickel	air	-7.6E+05	-3.0E+05	-9.8E+05	-8.9E+05	-1.1E+06	-9.2E+05	-8.6E+05	-1.1E+06	-8.5E+05	-7.8E+05	-8.1E+05	-9.4E+05
Nitrogen oxides (NO and NO_2 as NO_2)	air	-6.0E+04	6.4E+04	-4.2E+04	-9.9E+04	-1.0E+05	2.5E+03	5.3E+04	4.9E+04	-2.6E+04	4.7E+04	-1.0E+05	-6.0E+04
o-Xylene	air			1.1E+01		1.1E+01	4.5E+01	2.0E+01	2.0E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01
PAH, polycyclic aromatic hydrocarbons	air	-1.1E+08	-1.1E+08	-1.7E+08	-1.5E+08	-1.9E+08	-1.5E+08	-1.4E+08	-1.8E+08	-1.5E+08	-1.0E+08	-1.5E+08	-1.5E+08
Particulates, < 2.5 um	air	-1.5E+04	-1.5E+04	-2.1E+04	-1.9E+04	-2.3E+04	-1.9E+04	-1.9E+04	-2.1E+04	-1.9E+04	-1.6E+04	-2.0E+04	-1.9E+04
Particulates, > 2.5 um, and < 10um	air	-2.1E+04	-2.2E+04	-3.2E+04	-3.0E+04	-3.8E+04	-2.9E+04	-2.8E+04	-3.3E+04	-2.8E+04	-2.2E+04	-3.0E+04	-2.9E+04
Pentachlorophenol	air	-4.1E-01	1.4E-01	-4.4E-01	-4.2E-01	-5.1E-01	-4.5E-01	-4.5E-01	-4.7E-01	-4.4E-01	-4.8E-01	-5.1E-01	-4.5E-01
Phenol	air	8.4E-01	1.3E+00	1.1E+00	8.5E-01	1.2E+00	8.5E-01	8.6E-01	8.2E-01	8.6E-01	7.7E-01	1.2E+00	8.1E-01
Propylene oxide	air	4.3E+02	4.4E+02	4.0E+02	4.1E+02	5.1E+02	7.4E+02	7.8E+02	3.9E+02	4.9E+02	3.9E+02	3.9E+02	3.9E+02
Selenium	air	-9.0E+04	-9.0E+04	-1.3E+05	-1.1E+05	-1.4E+05	-1.2E+05	-1.2E+05	-1.3E+05	-1.1E+05	-1.1E+05	-1.2E+05	-1.2E+05
Sodium dichromate	air	-6.0E+03	-1.4E+04	-2.4E+05	-1.6E+05	-2.2E+05	-1.7E+05	-1.4E+05	-2.6E+05	-1.5E+05	-1.2E+04	-9.7E+04	-1.7E+05
Styrene	air	-1.0E-03	-8.6E-04	1.7E+00	1.6E+00	1.6E+00	5.3E+00	1.8E+00	1.9E+00	2.4E+00	2.5E+00	2.6E+00	2.3E+00
Sulfur dioxide	air	-1.2E+04	-1.2E+04	-1.6E+04	-1.6E+04	-1.7E+04	-1.6E+04	-1.5E+04	-1.7E+04	-1.5E+04	-1.4E+04	-1.7E+04	-1.6E+04
Sulphur oxides (SO_2 and SO_3 as SO_2)	air	-9.8E+02	-5.1E+02	-2.6E+03	-8.9E+02	-1.0E+03	-7.1E+03	-8.6E+03	-8.8E+03	-4.2E+03	-6.1E+03	-6.6E+03	-1.7E+03
Tetrachloroethylene	air	1.0E+00	-8.9E-02	5.5E-01	8.1E-01	5.7E-01	3.9E-01	1.1E-01	3.7E-02	7.5E-02	2.7E-01	2.2E-02	8.1E-01
Thallium	air	-5.9E+03	-5.9E+03	1.3E+05	1.3E+05	1.3E+05	6.2E+04	6.1E+04	6.1E+04	1.8E+05	1.8E+05	1.8E+05	1.9E+05
Tin	air	-6.3E-01	1.0E+01	-9.3E-01	-8.2E-01	-1.0E+00	-8.7E-01	-8.1E-01	-9.2E-01	-8.5E-01	-7.8E-01	-8.8E-01	-9.2E-01
Toluene	air	-6.2E+00	-1.6E+01	6.6E+01	4.3E+01	3.9E+01	2.0E+02	1.5E+02	1.5E+02	1.1E+02	1.4E+02	1.5E+02	7.6E+01
Trichloroethylene	air	8.7E+01	1.0E+00	5.0E+01	7.1E+01	5.2E+01	3.8E+01	1.6E+01	1.1E+01	1.4E+01	2.9E+01	9.5E+00	7.0E+01
Vanadium	air	-1.6E+05	-1.4E+05	-2.0E+05	-1.9E+05	-2.0E+05	-2.0E+05	-2.0E+05	-2.2E+05	-1.9E+05	-2.5E+05	-1.8E+05	-2.2E+05
Vinyl chloride	air	-5.6E+01	-6.9E+01	-9.9E+01	-8.4E+01	-1.1E+02	-9.1E+01	-8.9E+01	-1.1E+02	-9.0E+01	-6.8E+01	-9.7E+01	-8.7E+01
Zinc	air	2.6E+04	2.6E+04	4.3E+04	3.8E+04	4.9E+04	3.9E+04	3.6E+04	4.5E+04	3.7E+04	2.6E+04	3.9E+04	3.8E+04
Acenaphthene	water	-1.6E+02	-1.6E+02	-2.9E+02	-2.6E+02	-3.6E+02	-2.9E+02	-2.7E+02	-3.4E+02	-3.0E+02	-1.8E+02	-3.1E+02	-2.6E+02
Acenaphthylene	water	5.6E-01	-6.8E+00	-5.9E+00	-1.0E+01	-2.2E+01	-9.8E+00	-7.7E+00	-1.3E+01	-2.8E+01	-1.0E+00	-2.5E+01	-7.6E+00
Antimony	water	-1.1E+05	-4.0E+03	-1.2E+05	-3.0E+05	-1.5E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.3E+05	-1.8E+05	-1.2E+05
Arsenic	water	4.6E+04	1.7E+03	3.5E+04	4.4E+04	3.7E+04	1.4E+04	1.7E+04	3.7E+03	1.2E+04	1.8E+04	1.8E+04	2.1E+04
Arsenic, ion	water	-1.2E+05	-1.2E+05	-1.9E+05	-1.6E+05	-2.1E+05	-1.7E+05	-1.6E+05	-2.0E+05	-1.6E+05	-1.3E+05	-1.7E+05	-1.7E+05
Barite	water	-1.2E+05	-3.4E+05	-2.9E+05	-2.2E+05	7.6E+05	-2.5E+05	-2.3E+05	-2.8E+05	-9.4E+04	-1.8E+05	-2.9E+05	-2.2E+05
Barium	water	-1.8E+05	9.4E+04	-2.8E+05	-2.5E+05	-3.2E+05	-2.7E+05	-2.6E+05	-3.0E+05	-2.7E+05	-2.2E+05	-1.2E+05	-2.6E+05
Benzene	water	-4.4E+04	-4.3E+04	-5.3E+04	-5.1E+04	-6.5E+04	-5.3E+04	-5.1E+04	-5.6E+04	-5.4E+04	-4.6E+04	-6.1E+04	-5.1E+04
Benzene, chloro-	water	-2.6E-01	-1.2E-02	-1.3E-01	-3.1E-01	-2.6E-01	-3.4E-01	-3.3E-01	-3.7E-01	-3.4E-01	-1.5E+00	-3.2E-01	-7.2E-01
Beryllium	water	-3.9E+04	-3.9E+04	-5.5E+04	-4.8E+04	-6.2E+04	-5.2E+04	-5.0E+04	-5.9E+04	-5.0E+04	-4.3E+04	-2.9E+04	-5.1E+04
Cadmium	water	8.5E+01	2.3E+02	2.5E+01	4.8E+01	3.8E+01	1.4E+01	7.3E+00	-5.0E-01	6.8E+00	1.2E+01	6.1E+01	3.4E+01
Cadmium, ion	water	-1.0E+02	-1.1E+02	-1.0E+02	-1.2E+02	-1.3E+02	-1.1E+02	-1.1E+02	-1.2E+02	-1.6E+02	-1.5E+02	-1.5E+02	-1.2E+02
Chlorinated solvents, unspecified	water	-8.2E-01	-6.5E-01	-9.2E-01	-1.4E+00	-1.3E+00	-1.1E+00	-1.1E+00	-1.3E+00	-1.1E+00	-1.8E+00	-1.3E+00	-1.5E+00
Chloroform [Trichloromethane]	water	-6.9E-04	7.0E-05	-2.8E-04	-8.4E-04	-6.8E-04	-9.3E-04	-8.9E-04	-1.0E-03	-9.6E-04	-4.6E-03	-8.7E-04	-2.1E-03
Chromium	water	1.4E+02	8.2E+01	5.7E+01	1.1E+02	7.3E+01	5.5E+01	4.1E+01	4.1E+01	5.3E+01	3.7E+01	1.1E+02	6.4E+01
Chromium VI	water	-3.0E+03	-3.0E+03	-4.9E+03	-4.3E+03	-5.4E+03	-4.4E+03	-4.1E+03	-5.1E+03	-4.2E+03	-3.2E+03	-4.4E+03	-4.4E+03

Cobalt	water	-1.9E+03	-1.4E+03	-3.0E+03	-2.4E+03	-3.0E+03	-2.7E+03	-2.5E+03	-3.0E+03	-2.6E+03	-2.2E+03	1.5E+03	-2.8E+03
Copper	water	8.7E+01	3.7E+02	1.6E+01	5.7E+01	2.2E+01	5.4E+01	2.7E+01	3.9E+01	4.8E+01	4.5E+01	1.0E+02	5.5E+01
Copper, ion	water	1.0E+03	9.6E+02	1.0E+03	9.2E+02	1.2E+03	1.0E+03	1.0E+03	1.1E+03	1.1E+03	1.0E+03	1.2E+03	1.0E+03
Di(2-ethylhexyl)phthalate (DEHP)	water	3.5E+01	8.0E-01	1.6E+01	1.9E+01	2.0E+01	7.7E+00	4.6E+00	3.8E+00	3.7E+00	9.3E+00	4.6E+00	2.2E+01
Dichloromethane	water	-1.6E+00	-2.3E+00	-3.1E+00	-2.8E+00	-6.6E-01	-3.1E+00	-2.9E+00	-3.6E+00	-2.8E+00	-2.0E+00	-3.3E+00	-2.8E+00
Dichromate	water	-2.9E+00	-2.9E+00	-4.5E+00	-4.0E+00	-5.1E+00	-4.1E+00	-3.9E+00	-4.7E+00	-3.9E+00	-2.9E+00	-4.1E+00	-4.1E+00
Ethane, 1,1,1-trichloro-, HCFC-140	water	-7.2E-07	-8.5E-07	-7.0E-07	-8.3E-07	-9.6E-07	-7.7E-07	-7.5E-07	-7.9E-07	-1.2E-06	-7.2E-07	-1.1E-06	-7.7E-07
Ethene	water	-4.9E+00	-5.0E+00	-5.1E+00	-5.0E+00	-6.2E+00	-5.1E+00	-5.0E+00	-5.1E+00	-5.1E+00	-5.0E+00	-6.0E+00	-5.0E+00
Ethene, chloro-	water	-1.4E+00	-1.4E+00	-2.1E+00	-1.9E+00	-2.4E+00	-1.9E+00	-1.8E+00	-2.3E+00	-1.9E+00	-1.4E+00	-2.0E+00	-2.0E+00
Ethene, tetrachloro-	water	4.2E-07	3.6E-07	4.4E-07	4.1E-07	3.9E-07	4.1E-07	4.2E-07	4.1E-07	3.6E-07	4.2E-07	3.9E-07	4.2E-07
Ethene, trichloro-	water	3.7E-01	8.2E-03	1.8E-01	3.4E-01	2.8E-01	1.1E-01	8.5E-02	7.6E-02	9.5E-02	1.5E-01	4.7E-02	2.0E-01
Ethylbenzene	water	-1.6E+00	-1.7E+00	-3.1E+00	-2.7E+00	-3.7E+00	-3.0E+00	-2.8E+00	-3.6E+00	-3.2E+00	-1.9E+00	-3.3E+00	-2.7E+00
Ethylene dichloride	water	-3.0E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.6E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.3E+02	-3.5E+02	-3.1E+02
Ethylene oxide	water	-5.2E+02	-5.1E+02	-5.1E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.4E+02	-5.2E+02	-5.3E+02
Formaldehyde	water	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-6.0E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-5.9E-01	-4.9E-01
Fungicides, unspecified	water	8.5E-03	8.5E-03	8.5E-03	8.5E-03	1.0E-02	8.5E-03	8.5E-03	8.5E-03	8.5E-03	8.4E-03	1.0E-02	8.4E-03
Herbicides, unspecified	water	-3.9E-06	-3.0E-09	-1.9E-06	-4.6E-06	-3.8E-06	-5.1E-06	-4.9E-06	-5.6E-06	-5.2E-06	-2.3E-05	-4.7E-06	-1.1E-05
Insecticides, unspecified	water	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Lead	water	1.7E+03	1.5E+03	1.1E+03	1.2E+03	1.2E+03	1.7E+03	1.0E+03	9.1E+02	9.4E+02	9.6E+02	3.6E+03	1.1E+03
Mercury	water	-1.7E+02	-5.3E+02	-3.2E+02	-4.2E+01	-3.8E+02	-5.7E+02	-5.2E+02	-5.9E+02	-6.2E+02	-6.5E+02	1.3E+02	-5.6E+02
Metals (unspecified)	water	-5.9E-01	-5.8E-01	-5.7E-01	-5.9E-01	-5.8E-01	-5.9E-01	-5.9E-01	-5.9E-01	-6.0E-01	-5.9E-01	-5.9E-01	-5.9E-01
Molybdenum	water	-8.9E+04	3.9E+05	-1.1E+05	-1.1E+05	-1.3E+05	-1.1E+05	-1.1E+05	-1.2E+05	-1.1E+05	-1.0E+05	-1.2E+05	-1.1E+05
m-Xylene	water	6.2E-03	6.1E-03	6.4E-03	6.3E-03	6.3E-03	6.3E-03	6.3E-03	6.4E-03	6.1E-03	6.2E-03	6.2E-03	6.3E-03
Nickel	water	2.5E+04	7.3E+03	1.1E+04	2.0E+04	1.1E+04	1.5E+04	1.2E+04	1.1E+04	1.4E+04	1.5E+04	6.9E+04	1.5E+04
Nickel, ion	water	2.5E+03	1.1E+04	-6.8E+02	2.8E+03	9.3E+03	2.5E+02	2.1E+03	2.6E+03	7.5E+02	-3.8E+03	3.1E+03	-2.6E+03
o-Xylene	water	2.9E-04	2.9E-04	4.6E-04	4.0E-04	5.2E-04	4.2E-04	3.9E-04	4.8E-04	4.0E-04	2.9E-04	4.2E-04	4.1E-04
PAH, polycyclic aromatic hydrocarbons	water	-1.5E+05	-1.4E+05	-2.6E+05	-2.3E+05	-3.1E+05	-2.5E+05	-2.3E+05	-2.9E+05	-2.8E+05	-1.6E+05	-2.7E+05	-2.3E+05
Phenol	water	-5.0E-01	-5.5E-01	-8.4E-01	-9.6E-01	-1.0E+00	-8.5E-01	-8.1E-01	-9.9E-01	-9.0E-01	-6.0E-01	-1.1E+00	-7.6E-01
Phthalate, dibutyl-	water	1.4E-08	4.4E-09	1.6E-08	8.5E-09	8.4E-10	1.1E-08	1.2E-08	1.0E-08	-1.1E-08	1.4E-08	-6.7E-09	1.1E-08
Propylene oxide	water	1.7E+03	1.8E+03	1.6E+03	1.6E+03	2.0E+03	3.0E+03	3.1E+03	1.6E+03	2.0E+03	1.6E+03	1.6E+03	1.6E+03
Selenium	water	-1.0E+06	-1.0E+06	-1.6E+06	-1.4E+06	-1.8E+06	-1.5E+06	-1.4E+06	-1.7E+06	-1.4E+06	-1.1E+06	-1.4E+06	-1.5E+06
Thallium	water	-3.2E+04	-3.1E+04	-6.6E+04	-5.3E+04	-7.1E+04	-6.1E+04	-5.8E+04	-7.5E+04	-5.5E+04	-4.8E+04	-5.8E+04	-5.9E+04
Tin, ion	water	6.4E-01	6.2E-01	5.8E-01	5.3E-01	6.9E-01	6.1E-01	6.2E-01	6.0E-01	6.4E-01	6.1E-01	1.1E+00	6.0E-01
Toluene	water	-3.0E+00	-3.2E+00	-5.8E+00	-5.2E+00	-7.1E+00	-5.8E+00	-5.4E+00	-6.8E+00	-6.1E+00	-3.7E+00	-6.3E+00	-5.1E+00
Tributyltin compounds	water	-2.1E+03	-2.2E+03	-3.3E+03	-2.9E+03	-3.8E+03	-3.0E+03	-2.9E+03	-3.4E+03	-2.9E+03	-2.3E+03	-3.1E+03	-3.0E+03
Vanadium, ion	water	-4.3E+06	-4.3E+06	-7.1E+06	-6.1E+06	-7.9E+06	-6.3E+06	-6.0E+06	-7.4E+06	-6.1E+06	-4.5E+06	-6.4E+06	-6.4E+06
Xylene - all isomers [Dimethylbenzene]	water	-3.5E+00	-3.7E+00	-6.7E+00	-5.9E+00	-8.2E+00	-6.6E+00	-6.2E+00	-7.8E+00	-7.0E+00	-4.2E+00	-7.2E+00	-5.8E+00
Zinc	water	7.6E+02	-2.4E+01	1.5E+02	5.0E+02	4.0E+02	4.7E+02	1.8E+02	2.2E+02	3.3E+02	2.9E+02	1.6E+03	3.7E+02
2,4-D	soil	5.3E+01	5.3E+01	5.2E+01	5.3E+01	6.5E+01	5.3E+01	5.3E+01	5.2E+01	5.3E+01	5.2E+01	6.3E+01	5.2E+01
Antimony	soil	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.9E-01	8.1E-01	8.4E-01	8.3E-01

Arsenic	soil	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.0E+06	3.4E+05	1.9E+06	3.4E+05
Atrazine	soil	-6.4E-04	-5.7E-04	-6.2E-04	-7.3E-04	-7.9E-04	-7.0E-04	-6.9E-04	-7.2E-04	-9.6E-04	-1.0E-03	-9.4E-04	-8.1E-04
Barium	soil	-6.8E+03	-9.9E+03	-1.3E+04	-1.2E+04	-2.8E+03	-1.3E+04	-1.2E+04	-1.5E+04	-1.2E+04	-8.5E+03	-1.4E+04	-1.2E+04
Bentazone	soil	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.4E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.3E+00	1.9E+00
Cadmium	soil	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	1.3E+05	8.3E+03	8.3E+04	8.3E+03
Chlorothalonil	soil	5.5E+01	5.5E+01	5.4E+01	5.5E+01	5.4E+01	5.4E+01	5.4E+01	5.4E+01	5.5E+01	5.5E+01	5.4E+01	5.5E+01
Chromium	soil	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.4E+06	1.5E+05	9.3E+05	1.5E+05
Chromium VI	soil	-1.1E+05	-1.1E+05	-1.7E+05	-1.5E+05	-1.9E+05	-1.5E+05	-1.5E+05	-1.8E+05	-1.5E+05	-1.1E+05	-1.6E+05	-1.5E+05
Cobalt	soil	-1.7E+01	-1.8E+01	-1.7E+01	-1.8E+01	-2.0E+01	-1.7E+01	-1.7E+01	-1.7E+01	-1.6E+01	-1.8E+01	-1.9E+01	-1.7E+01
Copper	soil	-7.8E+03	-7.8E+03	-8.1E+03	-8.0E+03	-8.3E+03	-8.0E+03	-8.0E+03	-8.2E+03	5.4E+04	-7.8E+03	3.0E+04	-8.0E+03
Cypermethrin	soil	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03
Dinoseb	soil	-1.3E-01	-1.3E-01	-3.3E-01	-1.8E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.8E-01	-2.1E-01	-1.6E-01	-3.1E-01	-1.4E-01
Glyphosate	soil	5.9E-02	5.9E-02	5.9E-02	5.9E-02	7.2E-02	5.8E-02	5.8E-02	5.8E-02	5.9E-02	5.8E-02	7.0E-02	5.9E-02
Lead	soil	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.0E+06	5.9E+05	3.3E+06	5.9E+05
Linuron	soil	3.2E+02	3.2E+02	3.2E+02	3.2E+02	4.0E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.8E+02	3.2E+02
Mercury	soil	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.8E+04	1.9E+03	1.2E+04	1.9E+03
Metazachlor	soil	1.3E+02	7.2E+01	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.2E+02	1.3E+02
Metolachlor	soil	1.6E+02	1.6E+02	1.6E+02	1.6E+02	2.0E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.9E+02	1.6E+02
Molybdenum	soil	-2.1E+01	-2.2E+01	-2.1E+01	-2.2E+01	-2.5E+01	-2.1E+01	-2.1E+01	-2.1E+01	-2.1E+01	-2.4E+01	-2.4E+01	-2.2E+01
Nickel	soil	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	5.5E+05	6.3E+04	3.6E+05	6.3E+04
Pirimicarb	soil	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.9E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.7E-01	3.1E-01
Selenium	soil	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03
Thallium	soil	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.1E-03	8.2E-03	8.1E-03	8.2E-03
Tin	soil	-4.3E-04	1.2E-03	-4.5E-04	-1.9E-03	-2.6E-03	-2.2E-03	-1.9E-03	-3.1E-03	-1.9E-03	-1.3E-02	-1.5E-03	-6.4E-03
Vanadium	soil	-3.4E+02	-3.6E+02	-3.4E+02	-3.5E+02	-4.0E+02	-3.3E+02	-3.3E+02	-3.3E+02	-3.2E+02	-3.4E+02	-3.8E+02	-3.4E+02
Zinc	soil	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.7E+05	1.5E+04	1.1E+05	1.5E+04

Table 38: Norway freshwater ecotoxicity impacts by pollutant (kg 1,4-DCB equivalents)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		-9.2E+06	-9.0E+06	-1.6E+07	-1.3E+07	-1.7E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.0E+07	-9.9E+06	-1.1E+07	-1.4E+07
Acenaphthene	air	-8.2E-03	-8.4E-03	-1.1E-02	-9.6E-03	-1.2E-02	-1.0E-02	-9.8E-03	-1.1E-02	-9.6E-03	-9.3E-03	-1.1E-02	-9.8E-03
Acrolein	air	-1.2E+01	-1.1E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01
Antimony	air	-1.5E+00	1.3E+01	-1.3E+00	-9.4E-01	-1.4E+00	-6.1E-01	-9.0E-01	-1.6E+00	-5.2E-01	-6.4E-01	-5.3E-01	-7.9E-01
Arsenic	air	-1.1E+02	-3.2E+01	-1.3E+02	-1.3E+02	-1.6E+02	-1.1E+02	-1.1E+02	-1.2E+02	-1.3E+02	-1.2E+02	-1.2E+02	-1.4E+02
Barium	air	-1.5E+02	-1.6E+02	-2.1E+02	-1.9E+02	-2.3E+02	-2.1E+02	-2.1E+02	-2.4E+02	-2.0E+02	-1.9E+02	-2.1E+02	-2.0E+02
Benzene	air	-6.3E-03	-8.7E-03	-8.0E-03	-7.0E-03	-9.1E-03	-7.5E-03	-7.5E-03	-8.7E-03	-6.8E-03	-6.3E-03	-7.4E-03	-6.9E-03

Benzene, ethyl-	air	-5.9E-04	-6.0E-04	-8.4E-04	1.6E-02	-1.0E-03	-8.3E-04	-7.9E-04	-9.3E-04	-8.6E-04	-6.4E-04	-9.2E-04	-7.8E-04
Benzene, pentachloro-	air	4.7E-04	4.6E-04	5.0E-04	4.6E-04	5.7E-04	5.0E-04	5.0E-04	5.2E-04	5.1E-04	4.8E-04	5.6E-04	4.9E-04
Benzo(a)pyrene	air	-5.1E+02	-4.9E+02	-8.3E+02	-7.2E+02	-9.3E+02	-7.4E+02	-7.0E+02	-8.7E+02	-7.1E+02	-5.2E+02	-7.5E+02	-7.4E+02
Beryllium	air	-3.0E+02	-3.0E+02	-3.6E+02	-3.3E+02	-3.4E+02	-4.0E+02	-4.1E+02	-4.3E+02	-3.7E+02	-4.0E+02	-3.4E+02	-3.4E+02
Butadiene [1,3-Butadiene]	air	1.9E-05	1.8E-05	1.9E-05	1.8E-05	1.6E-05	1.9E-05	2.0E-05	1.9E-05	1.5E-05	2.0E-05	1.6E-05	1.8E-05
Cadmium	air	-3.4E+02	-1.2E+02	-4.6E+02	-4.4E+02	-5.3E+02	-3.9E+02	-3.8E+02	-4.5E+02	-4.0E+02	-4.0E+02	-4.3E+02	-4.6E+02
Carbon disulphide	air	1.9E+00	2.4E+00	3.8E+00	3.4E+00	4.4E+00	3.2E+00	3.1E+00	4.2E+00	2.5E+00	2.0E+00	3.1E+00	3.1E+00
Carbon tetrachloride [Tetrachloromethane]	air	4.4E-05	1.1E-05	1.0E-04	3.9E-05	2.7E-05	1.7E-05	5.3E-06	2.1E-06	3.9E-06	-9.6E-05	1.3E-06	-1.5E-06
Chlorinated Matter (unspecified, as Cl)	air	-2.7E-11	4.7E-14	-1.3E-11	-3.2E-11	-2.6E-11	-3.5E-11	-3.4E-11	-3.9E-11	-3.6E-11	-1.6E-10	-3.3E-11	-7.6E-11
Chloroform [Trichloromethane]	air	1.6E-05	-1.9E-07	8.9E-06	1.3E-05	9.1E-06	6.6E-06	2.5E-06	1.4E-06	2.0E-06	4.7E-06	1.2E-06	1.3E-05
Chromium VI	air	-4.7E-01	1.4E-01	2.5E+00	4.0E+00	4.7E+00	1.4E+00	1.5E+00	2.2E+00	3.8E+00	3.9E+00	3.7E+00	3.5E+00
Cobalt	air	-6.1E+02	2.9E+02	-7.7E+02	-6.7E+02	-7.9E+02	-7.3E+02	-7.2E+02	-7.7E+02	-7.0E+02	-7.8E+02	-6.9E+02	-7.6E+02
Copper	air	-8.6E+03	-7.3E+03	-1.3E+04	-1.2E+04	-1.5E+04	-1.2E+04	-1.1E+04	-1.3E+04	-1.1E+04	-8.8E+03	-1.2E+04	-1.2E+04
Dichloromethane	air	4.5E-06	-2.9E-06	1.4E-06	3.1E-06	1.5E-06	3.4E-07	-1.6E-06	-2.0E-06	-1.8E-06	-4.8E-07	-2.1E-06	3.1E-06
Dioxins and furans-as ITEQ	air	3.5E-02	2.7E+01	2.9E+00	7.9E-02	8.2E-02	9.7E+00	1.2E+01	1.2E+01	4.7E+00	8.3E+00	8.8E+00	1.2E+00
Dioxins and furans-as WHO TEQ	air	-2.6E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.7E-01	-2.6E-01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.7E+02	-2.8E+02	-2.8E+02	-2.8E+02	-3.5E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.7E+02	-3.3E+02	-2.8E+02
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.3E-03	2.1E-05	3.6E-04	1.0E-03	4.8E-04	6.8E-04	3.8E-04	6.1E-04	6.4E-04	4.0E-04	1.2E-04	9.2E-04
Ethane, 1,2-dichloro-	air	-7.5E-04	-8.0E-04	-8.6E-04	-8.1E-04	-1.0E-03	-8.3E-04	-8.3E-04	-8.6E-04	-8.3E-04	-8.8E-04	-9.8E-04	-8.5E-04
Ethylene [Ethene]	air	3.4E-10	1.3E-10	-1.4E-10	-8.9E-11	8.8E-11	-1.9E-10	-1.8E-10	-3.2E-10	-1.2E-10	3.2E-11	3.1E-10	-7.2E-11
Ethylene oxide [1,2-Epoxyethane]	air	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01
Formaldehyde [Methanal]	air	-8.4E+02	-9.5E+02	-1.1E+03	-1.0E+03	-1.2E+03	-1.0E+03	-1.0E+03	-1.1E+03	-1.0E+03	-9.2E+02	-1.0E+03	-1.0E+03
Hexachlorobenzene	air	4.1E-04	1.1E-03	4.4E-04	9.0E-04	1.9E-03	3.5E-04	4.7E-04	7.6E-04	3.6E-04	2.7E-04	8.0E-04	3.3E-04
Hydrocarbons (unspecified)	air	-3.0E-10	4.8E-09	-2.8E-10	-3.6E-10	-4.4E-10	-3.3E-10	-3.2E-10	-3.4E-10	-5.7E-10	-3.0E-10	-5.4E-10	-3.2E-10

Hydrogen fluoride	air	-6.6E+03	-7.3E+03	-1.1E+04	-9.4E+03	-1.2E+04	-1.0E+04	-9.7E+03	-1.2E+04	-9.8E+03	-7.3E+03	-1.0E+04	-9.8E+03
Lead	air	-1.1E+00	-1.7E+00	1.1E+01	3.8E+00	4.4E+00	7.6E+00	7.1E+00	1.3E+01	4.7E+00	-4.1E+00	7.7E+00	3.6E+00
Mercury	air	-2.6E+02	5.0E+02	-1.7E+02	-1.6E+02	-1.2E+02	-1.4E+02	-1.6E+02	-1.7E+02	-1.6E+02	-5.0E+01	-1.6E+02	-2.0E+02
Methyl bromide [Bromomethane]	air	2.0E-10	2.0E-10	3.2E-10	2.8E-10	3.6E-10	2.9E-10	2.7E-10	3.4E-10	2.8E-10	2.0E-10	2.9E-10	2.9E-10
Molybdenum	air	-2.4E+01	-2.2E+01	-3.6E+01	-3.1E+01	-3.3E+01	-3.5E+01	-3.4E+01	-4.0E+01	-3.2E+01	-3.7E+01	-3.0E+01	-3.5E+01
m-Xylene	air	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-4.1E-04	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-4.0E-04	-3.4E-04
Nickel	air	-1.4E+04	-5.5E+03	-1.8E+04	-1.6E+04	-1.9E+04	-1.7E+04	-1.6E+04	-1.9E+04	-1.5E+04	-1.4E+04	-1.5E+04	-1.7E+04
o-Xylene	air			8.2E-03		8.2E-03	3.4E-02	1.5E-02	1.5E-02	1.2E-02	1.2E-02	1.2E-02	1.2E-02
PAH, polycyclic aromatic hydrocarbons	air	-3.2E+04	-3.2E+04	-5.2E+04	-4.5E+04	-5.8E+04	-4.6E+04	-4.3E+04	-5.4E+04	-4.4E+04	-3.1E+04	-4.6E+04	-4.6E+04
Pentachlorophenol	air	-8.5E-01	2.9E-01	-9.0E-01	-8.8E-01	-1.1E+00	-9.3E-01	-9.4E-01	-9.6E-01	-9.1E-01	-1.0E+00	-1.1E+00	-9.3E-01
Phenol	air	2.5E+00	3.7E+00	3.1E+00	2.5E+00	3.5E+00	2.5E+00	2.5E+00	2.4E+00	2.5E+00	2.2E+00	3.4E+00	2.4E+00
Propylene oxide	air	1.3E-02	1.3E-02	1.2E-02	1.2E-02	1.5E-02	2.2E-02	2.3E-02	1.1E-02	1.4E-02	1.1E-02	1.1E-02	1.1E-02
Selenium	air	-1.0E+03	-1.0E+03	-1.5E+03	-1.3E+03	-1.6E+03	-1.4E+03	-1.3E+03	-1.5E+03	-1.3E+03	-1.2E+03	-1.4E+03	-1.4E+03
Sodium dichromate	air	-1.4E-02	-3.1E-02	-5.3E-01	-3.5E-01	-4.9E-01	-3.9E-01	-3.2E-01	-5.9E-01	-3.4E-01	-2.8E-02	-2.2E-01	-3.9E-01
Styrene	air	-1.1E-06	-9.3E-07	1.8E-03	1.7E-03	1.7E-03	5.7E-03	2.0E-03	2.0E-03	2.6E-03	2.7E-03	2.7E-03	2.5E-03
Tetrachloroethylene	air	7.7E-05	-6.6E-06	4.1E-05	6.1E-05	4.3E-05	2.9E-05	7.9E-06	2.8E-06	5.6E-06	2.0E-05	1.6E-06	6.0E-05
Thallium	air	-2.1E+01	-2.1E+01	4.6E+02	4.6E+02	4.6E+02	2.2E+02	2.2E+02	2.2E+02	6.6E+02	6.5E+02	6.6E+02	6.7E+02
Tin	air	-9.2E-01	1.5E+01	-1.4E+00	-1.2E+00	-1.5E+00	-1.3E+00	-1.2E+00	-1.4E+00	-1.2E+00	-1.2E+00	-1.3E+00	-1.4E+00
Toluene	air	-1.3E-03	-3.5E-03	1.4E-02	9.3E-03	8.4E-03	4.3E-02	3.3E-02	3.3E-02	2.3E-02	3.1E-02	3.1E-02	1.6E-02
Trichloroethylene	air	9.7E-05	1.2E-06	5.6E-05	7.8E-05	5.8E-05	4.2E-05	1.8E-05	1.2E-05	1.5E-05	3.2E-05	1.1E-05	7.8E-05
Vanadium	air	-4.5E+04	-3.9E+04	-5.7E+04	-5.2E+04	-5.5E+04	-5.6E+04	-5.5E+04	-6.1E+04	-5.4E+04	-7.0E+04	-5.1E+04	-6.1E+04
Vinyl chloride	air	-1.9E-06	-2.3E-06	-3.4E-06	-2.8E-06	-3.8E-06	-3.1E-06	-3.0E-06	-3.7E-06	-3.1E-06	-2.3E-06	-3.3E-06	-3.0E-06
Zinc	air	4.5E+03	4.5E+03	7.4E+03	6.4E+03	8.3E+03	6.6E+03	6.2E+03	7.7E+03	6.3E+03	4.4E+03	6.6E+03	6.6E+03
Acenaphthene	water	-1.5E+01	-1.5E+01	-2.8E+01	-2.5E+01	-3.4E+01	-2.8E+01	-2.6E+01	-3.2E+01	-2.9E+01	-1.8E+01	-3.0E+01	-2.5E+01
Acenaphthylene	water	5.4E-02	-6.6E-01	-5.7E-01	-9.8E-01	-2.1E+00	-9.4E-01	-7.5E-01	-1.3E+00	-2.7E+00	-9.8E-02	-2.4E+00	-7.3E-01
Antimony	water	-3.3E+02	-1.2E+01	-3.7E+02	-8.9E+02	-4.5E+02	-3.6E+02	-3.6E+02	-3.7E+02	-3.5E+02	-3.9E+02	-5.3E+02	-3.7E+02
Arsenic	water	6.1E+03	2.3E+02	4.7E+03	5.8E+03	4.9E+03	1.9E+03	2.3E+03	5.0E+02	1.7E+03	2.5E+03	2.4E+03	2.7E+03
Arsenic, ion	water	-1.6E+04	-1.6E+04	-2.5E+04	-2.2E+04	-2.8E+04	-2.3E+04	-2.2E+04	-2.7E+04	-2.2E+04	-1.7E+04	-2.3E+04	-2.3E+04
Barite	water	-3.6E+04	-1.0E+05	-8.6E+04	-6.7E+04	2.3E+05	-7.3E+04	-6.8E+04	-8.4E+04	-2.8E+04	-5.4E+04	-8.6E+04	-6.6E+04

Barium	water	-5.5E+04	2.8E+04	-8.3E+04	-7.5E+04	-9.6E+04	-8.0E+04	-7.7E+04	-9.1E+04	-7.9E+04	-6.5E+04	-3.4E+04	-7.7E+04
Benzene	water	-2.1E+00	-2.1E+00	-2.6E+00	-2.5E+00	-3.2E+00	-2.6E+00	-2.5E+00	-2.7E+00	-2.6E+00	-2.2E+00	-3.0E+00	-2.5E+00
Benzene, chloro-	water	-9.0E-03	-4.1E-04	-4.5E-03	-1.1E-02	-8.9E-03	-1.2E-02	-1.1E-02	-1.3E-02	-1.2E-02	-5.2E-02	-1.1E-02	-2.5E-02
Beryllium	water	-2.1E+05	-2.1E+05	-3.0E+05	-2.6E+05	-3.4E+05	-2.8E+05	-2.8E+05	-3.2E+05	-2.7E+05	-2.4E+05	-1.6E+05	-2.8E+05
Cadmium	water	3.2E+03	8.5E+03	9.5E+02	1.8E+03	1.4E+03	5.4E+02	2.8E+02	-1.9E+01	2.6E+02	4.7E+02	2.3E+03	1.3E+03
Cadmium, ion	water	-3.9E+03	-4.0E+03	-3.9E+03	-4.7E+03	-4.8E+03	-4.3E+03	-4.2E+03	-4.4E+03	-6.0E+03	-5.5E+03	-5.7E+03	-4.7E+03
Chlorinated solvents, unspecified	water	-8.7E-02	-6.9E-02	-9.8E-02	-1.5E-01	-1.4E-01	-1.2E-01	-1.1E-01	-1.4E-01	-1.2E-01	-1.9E-01	-1.4E-01	-1.5E-01
Chloroform [Trichloromethane]	water	-2.1E-06	2.1E-07	-8.6E-07	-2.5E-06	-2.1E-06	-2.8E-06	-2.7E-06	-3.2E-06	-2.9E-06	-1.4E-05	-2.6E-06	-6.4E-06
Chromium	water	2.6E+02	1.5E+02	1.1E+02	2.1E+02	1.4E+02	1.0E+02	7.5E+01	7.7E+01	9.9E+01	6.9E+01	2.0E+02	1.2E+02
Chromium VI	water	-1.3E+04	-1.3E+04	-2.2E+04	-1.9E+04	-2.4E+04	-2.0E+04	-1.8E+04	-2.3E+04	-1.9E+04	-1.4E+04	-2.0E+04	-2.0E+04
Cobalt	water	-6.2E+04	-4.6E+04	-9.5E+04	-7.5E+04	-9.7E+04	-8.6E+04	-7.9E+04	-9.4E+04	-8.3E+04	-7.0E+04	4.8E+04	-9.1E+04
Copper	water	4.3E+04	1.8E+05	8.2E+03	2.9E+04	1.1E+04	2.7E+04	1.4E+04	1.9E+04	2.4E+04	2.2E+04	5.1E+04	2.8E+04
Copper, ion	water	5.1E+05	4.8E+05	5.0E+05	4.6E+05	5.9E+05	5.2E+05	5.2E+05	5.3E+05	5.2E+05	5.0E+05	5.8E+05	5.0E+05
Di(2-ethylhexyl)phthalate (DEHP)	water	1.5E+01	3.3E-01	6.5E+00	8.0E+00	8.2E+00	3.2E+00	1.9E+00	1.6E+00	1.5E+00	3.9E+00	1.9E+00	8.9E+00
Dichloromethane	water	-1.0E-02	-1.5E-02	-2.0E-02	-1.8E-02	-4.2E-03	-2.0E-02	-1.8E-02	-2.3E-02	-1.8E-02	-1.3E-02	-2.1E-02	-1.8E-02
Dichromate	water	-1.3E+01	-1.3E+01	-2.0E+01	-1.8E+01	-2.3E+01	-1.8E+01	-1.7E+01	-2.1E+01	-1.7E+01	-1.3E+01	-1.8E+01	-1.8E+01
Ethane, 1,1,1-trichloro-, HCFC-140	water	-4.2E-09	-5.0E-09	-4.1E-09	-4.9E-09	-5.6E-09	-4.5E-09	-4.4E-09	-4.6E-09	-6.9E-09	-4.2E-09	-6.7E-09	-4.5E-09
Ethene	water	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.1E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.0E-01	-1.7E-01
Ethene, chloro-	water	-2.4E-04	-2.5E-04	-3.9E-04	-3.4E-04	-4.4E-04	-3.5E-04	-3.3E-04	-4.0E-04	-3.4E-04	-2.6E-04	-3.5E-04	-3.5E-04
Ethene, tetrachloro-	water	4.6E-08	3.9E-08	4.8E-08	4.5E-08	4.2E-08	4.5E-08	4.5E-08	4.5E-08	3.9E-08	4.6E-08	4.2E-08	4.5E-08
Ethene, trichloro-	water	9.6E-04	2.2E-05	4.8E-04	8.9E-04	7.3E-04	2.8E-04	2.2E-04	2.0E-04	2.5E-04	4.0E-04	1.2E-04	5.3E-04
Ethylbenzene	water	-1.0E+00	-1.1E+00	-2.0E+00	-1.8E+00	-2.4E+00	-2.0E+00	-1.8E+00	-2.3E+00	-2.1E+00	-1.2E+00	-2.1E+00	-1.7E+00
Ethylene dichloride	water	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.9E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.6E-01	-2.8E-01	-2.4E-01
Ethylene oxide	water	-4.4E-01	-4.3E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.6E-01	-4.4E-01	-4.5E-01
Formaldehyde	water	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.6E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.4E+03	-3.7E+03
Fungicides, unspecified	water	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.7E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.5E-03	4.6E-03
Herbicides, unspecified	water	-3.4E-05	-2.6E-08	-1.6E-05	-4.0E-05	-3.3E-05	-4.4E-05	-4.2E-05	-4.9E-05	-4.5E-05	-2.0E-04	-4.1E-05	-9.5E-05

Insecticides, unspecified	water	8.7E+00	8.7E+00	8.7E+00	8.7E+00	1.1E+01	8.7E+00	8.7E+00	8.7E+00	8.7E+00	8.6E+00	1.0E+01	8.7E+00
Lead	water	6.4E+02	5.8E+02	4.0E+02	4.4E+02	4.6E+02	6.5E+02	3.9E+02	3.4E+02	3.6E+02	3.6E+02	1.3E+03	4.2E+02
Mercury	water	-1.1E+02	-3.3E+02	-2.0E+02	-2.6E+01	-2.4E+02	-3.5E+02	-3.2E+02	-3.6E+02	-3.8E+02	-4.0E+02	7.9E+01	-3.4E+02
Metals (unspecified)	water	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02
Molybdenum	water	-6.3E+03	2.8E+04	-8.2E+03	-7.6E+03	-9.3E+03	-7.9E+03	-7.8E+03	-8.7E+03	-7.6E+03	-7.3E+03	-8.6E+03	-7.9E+03
m-Xylene	water	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02
Nickel	water	1.7E+05	5.2E+04	7.6E+04	1.4E+05	7.5E+04	1.0E+05	8.3E+04	7.9E+04	9.6E+04	1.1E+05	4.9E+05	1.1E+05
Nickel, ion	water	1.8E+04	7.5E+04	-4.8E+03	2.0E+04	6.6E+04	1.8E+03	1.5E+04	1.8E+04	5.4E+03	-2.7E+04	2.2E+04	-1.9E+04
o-Xylene	water	3.8E-04	3.8E-04	6.1E-04	5.3E-04	6.9E-04	5.4E-04	5.1E-04	6.3E-04	5.2E-04	3.8E-04	5.5E-04	5.4E-04
PAH, polycyclic aromatic hydrocarbons	water	-1.4E+04	-1.3E+04	-2.4E+04	-2.2E+04	-3.0E+04	-2.4E+04	-2.2E+04	-2.7E+04	-2.6E+04	-1.5E+04	-2.6E+04	-2.2E+04
Phenol	water	-2.4E+03	-2.7E+03	-4.0E+03	-4.6E+03	-5.0E+03	-4.1E+03	-3.9E+03	-4.8E+03	-4.3E+03	-2.9E+03	-5.1E+03	-3.6E+03
Phthalate, dibutyl-	water	2.1E-06	6.5E-07	2.4E-06	1.3E-06	1.2E-07	1.6E-06	1.8E-06	1.5E-06	-1.7E-06	2.0E-06	-9.8E-07	1.7E-06
Propylene oxide	water	2.6E+00	2.6E+00	2.4E+00	2.5E+00	3.1E+00	4.5E+00	4.7E+00	2.3E+00	2.9E+00	2.3E+00	2.4E+00	2.4E+00
Selenium	water	-4.5E+04	-4.5E+04	-7.1E+04	-6.2E+04	-8.0E+04	-6.4E+04	-6.1E+04	-7.4E+04	-6.1E+04	-4.7E+04	-5.9E+04	-6.4E+04
Thallium	water	-9.4E+02	-9.1E+02	-1.9E+03	-1.6E+03	-2.1E+03	-1.8E+03	-1.7E+03	-2.2E+03	-1.6E+03	-1.4E+03	-1.7E+03	-1.7E+03
Tin, ion	water	1.9E+02	1.8E+02	1.7E+02	1.5E+02	2.0E+02	1.8E+02	1.8E+02	1.8E+02	1.9E+02	1.8E+02	3.2E+02	1.7E+02
Toluene	water	-2.9E+00	-3.1E+00	-5.4E+00	-4.9E+00	-6.7E+00	-5.4E+00	-5.1E+00	-6.4E+00	-5.8E+00	-3.5E+00	-5.9E+00	-4.8E+00
Tributyltin compounds	water	-2.8E+05	-2.9E+05	-4.4E+05	-3.9E+05	-5.1E+05	-4.0E+05	-3.8E+05	-4.6E+05	-3.9E+05	-3.0E+05	-4.1E+05	-4.0E+05
Vanadium, ion	water	-9.2E+06	-9.2E+06	-1.5E+07	-1.3E+07	-1.7E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.3E+07	-9.7E+06	-1.4E+07	-1.4E+07
Xylene - all isomers [Dimethylbenzene]	water	-4.7E+00	-5.0E+00	-8.9E+00	-7.9E+00	-1.1E+01	-8.8E+00	-8.2E+00	-1.0E+01	-9.3E+00	-5.6E+00	-9.6E+00	-7.8E+00
Zinc	water	6.2E+04	-1.9E+03	1.2E+04	4.1E+04	3.3E+04	3.8E+04	1.5E+04	1.8E+04	2.7E+04	2.4E+04	1.3E+05	3.0E+04
2,4-D	soil	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.1E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.0E+01	3.3E+01
Antimony	soil	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.1E-03	1.9E-03	2.0E-03	2.0E-03
Arsenic	soil	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	4.6E+04	5.2E+03	3.0E+04	5.2E+03
Atrazine	soil	-1.0E-02	-9.3E-03	-1.0E-02	-1.2E-02	-1.3E-02	-1.1E-02	-1.1E-02	-1.2E-02	-1.6E-02	-1.7E-02	-1.5E-02	-1.3E-02
Barium	soil	-2.4E+03	-3.4E+03	-4.6E+03	-4.2E+03	-9.8E+02	-4.6E+03	-4.2E+03	-5.4E+03	-4.1E+03	-3.0E+03	-4.9E+03	-4.1E+03
Bentazone	soil	1.0E+00	1.1E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Cadmium	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	2.0E+04	1.3E+03	1.3E+04	1.3E+03

Chlorothalonil	soil	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01
Chromium	soil	5.4E+02	5.3E+02	5.3E+02	5.3E+02	5.4E+02	5.3E+02	5.3E+02	5.3E+02	5.0E+03	5.3E+02	3.2E+03	5.3E+02
Chromium VI	soil	-9.1E+02	-9.3E+02	-1.4E+03	-1.2E+03	-1.6E+03	-1.3E+03	-1.2E+03	-1.5E+03	-1.2E+03	-9.2E+02	-1.3E+03	-1.3E+03
Cobalt	soil	-4.5E+01	-4.7E+01	-4.6E+01	-4.7E+01	-5.3E+01	-4.5E+01	-4.4E+01	-4.4E+01	-4.3E+01	-4.7E+01	-5.1E+01	-4.6E+01
Copper	soil	-1.9E+05	-1.9E+05	-2.0E+05	-1.9E+05	-2.0E+05	-2.0E+05	-1.9E+05	-2.0E+05	1.3E+06	-1.9E+05	7.2E+05	-2.0E+05
Cypermethrin	soil	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.4E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.3E+05	1.1E+05
Dinoseb	soil	-4.7E+00	-4.8E+00	-1.2E+01	-6.4E+00	-6.2E+00	-6.0E+00	-6.2E+00	-6.4E+00	-7.4E+00	-5.8E+00	-1.1E+01	-5.1E+00
Glyphosate	soil	1.8E+01	1.8E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01
Lead	soil	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.2E+04	3.7E+03	2.1E+04	3.7E+03
Linuron	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03
Mercury	soil	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	6.8E+03	7.2E+02	4.4E+03	7.2E+02
Metazachlor	soil	1.0E+01	5.7E+00	1.0E+01	1.0E+01	9.9E+00	1.0E+01	1.0E+01	1.0E+01	9.4E+00	1.0E+01	9.5E+00	1.0E+01
Metolachlor	soil	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.2E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.1E+04	2.6E+04
Molybdenum	soil	-1.4E+00	-1.5E+00	-1.5E+00	-1.5E+00	-1.7E+00	-1.4E+00	-1.4E+00	-1.4E+00	-1.4E+00	-1.7E+00	-1.6E+00	-1.5E+00
Nickel	soil	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.1E+06	1.3E+05	7.4E+05	1.3E+05
Pirimicarb	soil	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.5E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.4E+01	2.0E+01
Selenium	soil	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04
Thallium	soil	5.8E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.7E-05	5.8E-05
Tin	soil	-8.1E-04	2.3E-03	-8.4E-04	-3.5E-03	-4.9E-03	-4.2E-03	-3.6E-03	-5.8E-03	-3.6E-03	-2.5E-02	-2.8E-03	-1.2E-02
Vanadium	soil	-2.7E+02	-2.8E+02	-2.7E+02	-2.8E+02	-3.1E+02	-2.6E+02	-2.6E+02	-2.6E+02	-2.6E+02	-2.7E+02	-3.0E+02	-2.7E+02
Zinc	soil	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	5.1E+05	4.5E+04	3.3E+05	4.5E+04

Table 39: France GHG emissions impacts by pollutant (kg CO_2 equivalent)

Substances	Landfill	Incineration	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-1.3E+07	-3.2E+07	-3.4E+07	-4.1E+07	-4.0E+07	-4.1E+07	-4.8E+07	-5.8E+07	-3.8E+07	-3.5E+07	-6.1E+07	-2.7E+07
Carbon dioxide (CO_2)	4.9E+04	4.9E+04	4.9E+04	5.3E+04	6.0E+04	4.9E+04	4.9E+04	4.9E+04	4.9E+04	4.8E+04	6.0E+04	4.9E+04
Carbon dioxide, fossil	-3.5E+07	-2.6E+07	-4.5E+07	-5.8E+07	-5.1E+07	-3.6E+07	-3.4E+07	-3.8E+07	-2.7E+07	-2.9E+07	-5.0E+07	-4.0E+07
Carbon Monoxide (CO)	5.3E+04	-1.7E+03	4.1E+04	5.3E+04	3.4E+04	6.5E+03	1.2E+04	5.1E+02	-3.1E+02	2.0E+04	5.4E+03	3.7E+04
Carbon monoxide, biogenic	-3.0E+05	-3.0E+05	-4.9E+05	-4.3E+05	-5.5E+05	-4.4E+05	-4.1E+05	-5.1E+05	-4.2E+05	-3.0E+05	-4.4E+05	-4.4E+05

Carbon monoxide, fossil	-1.4E+05	-1.6E+05	-1.9E+05	-2.4E+05	-2.4E+05	-1.9E+05	-1.8E+05	-2.0E+05	-1.9E+05	-1.5E+05	-2.2E+05	-1.8E+05
Carbon tetrachloride [Tetrachloromethane]	2.4E+02	5.7E+01	5.7E+02	2.1E+02	1.5E+02	9.6E+01	3.0E+01	1.3E+01	2.2E+01	-5.3E+02	7.9E+00	-8.7E+00
Chlorinated Matter (unspecified, as Cl)	-8.2E-05	-2.1E-06	-3.9E-05	-9.9E-05	-8.0E-05	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-4.9E-04	-9.8E-05	-2.3E-04
Dichloromethane	1.2E+00	-7.4E-01	3.6E-01	8.2E-01	4.0E-01	9.2E-02	-4.1E-01	-5.2E-01	-4.6E-01	-1.2E-01	-5.5E-01	8.1E-01
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-3.2E+01	-3.4E+01	-1.3E+01	-2.6E+01	-3.2E+01	-2.7E+01	-2.7E+01	-2.3E+01	-3.0E+01	-2.1E+01	-2.8E+01	-2.8E+01
Ethane, 1,1,1-trichloro-, HCFC-140	1.6E+03	2.6E+01	4.3E+02	1.2E+03	5.7E+02	8.2E+02	4.5E+02	7.3E+02	7.6E+02	4.8E+02	1.5E+02	1.1E+03
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2.6E+04	4.4E+02	6.3E+03	1.9E+04	1.0E+04	1.2E+04	7.1E+03	1.1E+04	1.2E+04	7.8E+03	2.6E+03	1.7E+04
Ethane, 1,1-difluoro-, HFC-152a	-8.6E-01	-1.1E+00	-9.7E-01	-1.1E+00	-1.1E+00	-8.8E-01	-8.6E-01	-8.7E-01	-8.0E-01	-9.6E-01	-9.2E-01	-9.3E-01
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	3.0E+04	-1.2E+03	6.1E+03	2.2E+04	1.1E+04	1.4E+04	6.9E+03	1.2E+04	1.3E+04	8.5E+03	1.0E+03	2.0E+04
Ethane, 1-chloro-1,1-difluoro-, HCFC-142	2.1E+03	3.5E+01	5.9E+02	1.6E+03	7.8E+02	1.1E+03	6.2E+02	9.8E+02	1.0E+03	6.5E+02	2.0E+02	1.5E+03
Ethane, 2,2-dichloro-1,1,1-tri-fluoro-, HCFC-123	2.2E+01	3.7E-01	5.4E+00	1.6E+01	8.6E+00	1.1E+01	6.0E+00	9.0E+00	9.8E+00	6.7E+00	2.2E+00	1.4E+01
Ethane, 2-chloro-1,1,1,2-tetra-fluoro-, HCFC-124	8.3E+01	1.3E+00	2.3E+01	6.3E+01	3.0E+01	4.3E+01	2.4E+01	3.8E+01	4.0E+01	2.5E+01	7.8E+00	5.8E+01
Hydrocarbons (unspecified)	-1.0E+02	1.7E+03	-9.9E+01	-1.3E+02	-1.5E+02	-1.2E+02	-1.1E+02	-1.2E+02	-2.0E+02	-1.0E+02	-1.9E+02	-1.1E+02
Methane, (unspecified)	2.9E+07	5.4E+05	2.4E+07	2.7E+07	2.1E+07	1.1E+07	3.7E+06	1.5E+06	1.2E+06	9.8E+06	3.7E+06	2.4E+07
Methane, biogenic	8.8E+03	7.6E+03	3.3E+04	2.6E+04	3.9E+04	7.1E+04	4.5E+04	4.5E+04	8.7E+03	4.0E+04	4.4E+04	4.2E+04
Methane, bromochlorodifluoro-, Halon 1211	8.3E+01	-2.9E+02	5.4E+01	4.5E+01	1.8E+03	7.4E+01	7.9E+01	8.9E+01	3.5E+02	3.4E+01	9.0E+01	5.3E+01
Methane, bromotrifluoro-, Halon 1301	-5.3E+02	-5.6E+02	-9.3E+02	-9.0E+02	-1.1E+03	-8.6E+02	-7.9E+02	-9.8E+02	-8.9E+02	-5.6E+02	-9.1E+02	-8.1E+02
Methane, chlorodifluoro-, HCFC-22	3.0E+03	-8.3E+02	8.3E+02	2.2E+03	6.9E+03	1.6E+03	9.4E+02	1.5E+03	2.4E+03	8.1E+02	4.1E+02	2.0E+03
Methane, chlorotrifluoro-, CFC-13	1.1E+04	1.9E+02	2.8E+03	8.4E+03	4.5E+03	5.5E+03	3.1E+03	4.7E+03	5.1E+03	3.5E+03	1.1E+03	7.5E+03
Methane, dichlorodifluoro-, CFC-12	6.7E+04	1.1E+03	1.9E+04	5.1E+04	2.5E+04	3.5E+04	1.9E+04	3.1E+04	3.3E+04	2.0E+04	6.4E+03	4.7E+04
Methane, fossil	-2.6E+06	-3.8E+06	-6.3E+06	-4.9E+06	-1.6E+06	-1.0E+07	-1.3E+07	-1.4E+07	-6.8E+06	-1.0E+07	-8.3E+06	-4.3E+06
Methane, tetrafluoro-, FC-14	-3.8E+06	-3.8E+06	-6.3E+06	-5.5E+06	-7.1E+06	-5.6E+06	-5.3E+06	-6.6E+06	-5.4E+06	-3.8E+06	-5.6E+06	-5.6E+06
Methane, trichlorofluoro-, CFC-11	1.5E+03	2.6E+01	3.7E+02	1.1E+03	5.9E+02	7.2E+02	4.1E+02	6.2E+02	6.7E+02	4.6E+02	1.5E+02	9.9E+02
Methane, trifluoro-, HFC-23	-1.2E+00	-5.9E-01	-8.9E-01	-1.5E+00	-1.3E+00	-1.5E+00	-1.4E+00	-1.6E+00	-1.4E+00	-5.1E+00	-1.4E+00	-2.7E+00
Methyl bromide [Bromomethane]	3.1E-08	3.1E-08	4.9E-08	4.3E-08	5.6E-08	4.4E-08	4.2E-08	5.1E-08	4.2E-08	3.0E-08	4.5E-08	4.4E-08
Methyl chloride [Chloromethane]	3.1E+00	1.8E-01	1.8E+00	2.5E+00	1.9E+00	1.4E+00	6.7E-01	5.0E-01	5.9E-01	1.1E+00	4.5E-01	2.5E+00
Nitrous oxide	-2.1E+05	1.8E+06	-1.4E+05	-2.0E+05	-1.5E+05	2.6E+05	9.2E+04	8.3E+04	7.3E+04	-8.9E+05	5.4E+04	-2.8E+05
Sulphur hexafluoride	-5.0E+04	-5.1E+04	-5.4E+04	-5.3E+04	-6.4E+04	-5.3E+04	-5.3E+04	-5.5E+04	-5.3E+04	-5.5E+04	-6.1E+04	-5.4E+04

Table 40: France abiotic resource depletion by pollutant (kg antimony equivalents)

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-3.3E+05	-4.7E+05	-6.2E+05	-5.8E+05	-1.7E+05	-8.5E+05	-9.8E+05	-1.1E+06	-5.9E+05	-8.1E+05	-7.4E+05	-4.8E+05
Aluminium, 24% in bauxite, 11% in crude ore, in ground	-2.4E-02	-2.4E-02	-4.0E-02	-3.4E-02	-4.4E-02	-3.5E-02	-3.3E-02	-4.1E-02	-3.4E-02	-2.4E-02	-3.6E-02	-3.5E-02
Anhydrite, in ground	-1.6E-03	-1.6E-03	-1.6E-03	-3.5E-03	-1.9E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-2.9E-03	-1.6E-03
Barite, 15% in crude ore, in ground	-4.5E-01	-7.9E-01	-8.2E-01	-8.6E-01	-3.9E-02	-7.2E-01	-6.5E-01	-8.0E-01	-5.8E-01	-5.2E-01	-7.5E-01	-7.1E-01
Borax, in ground	1.6E-03	1.7E-01	1.3E-01	5.3E-03	1.8E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-02	1.6E-03
Calcite, in ground	-2.5E-04	1.9E-04	-4.1E-04	-4.0E-04	-4.8E-04	-3.5E-04	-3.2E-04	-3.6E-04	-3.4E-04	-3.6E-04	-3.3E-04	-3.2E-04
Cerium, in ground	7.2E-18	7.1E-18	1.2E-17	1.0E-17	1.4E-17	1.1E-17	1.0E-17	1.2E-17	1.0E-17	7.5E-18	1.1E-17	1.1E-17
Chromium, 25.5 in chromite, 11.6% in crude ore, in ground	1.2E-01	9.5E-01	4.1E-01	6.7E-01	8.7E-01	4.6E-01	5.7E-01	7.2E-01	4.7E-01	-2.8E-01	4.1E-01	3.8E-03
Chrysotile, in ground	-3.4E-09	-1.8E-09	-7.0E-09	-5.9E-09	-7.2E-09	-6.1E-09	-5.6E-09	-7.4E-09	-5.7E-09	-1.3E-08	-5.1E-09	-9.3E-09
Cinnabar, in ground	-1.4E-01	-7.6E-02	-9.0E-02	-2.3E-01	-2.8E-01	-2.4E-01	-2.2E-01	-3.0E-01	-2.3E-01	-5.2E-01	-2.1E-01	-3.7E-01
Coal (in ground)	-9.5E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03
Coal, brown, in ground	-3.3E+04	-3.4E+04	-4.3E+04	-4.0E+04	-4.9E+04	-4.2E+04	-4.1E+04	-4.6E+04	-4.0E+04	-3.8E+04	-4.4E+04	-4.2E+04
Coal, hard, unspecified, in ground	-1.5E+05	-2.0E+05	-3.9E+05	-2.3E+05	-2.3E+05	-6.3E+05	-7.7E+05	-8.2E+05	-4.3E+05	-6.1E+05	-4.5E+05	-2.6E+05
Cobalt, in ground	1.0E-07	-1.9E-08	-2.6E-07	-2.9E-07	-5.2E-07	-3.0E-07	-2.3E-07	-5.6E-07	-5.4E-07	2.4E-08	-5.2E-07	-2.1E-07
Colemanite, in ground	5.6E-02	5.7E-02	5.3E-02	5.4E-02	5.2E-02	5.4E-02	5.4E-02	5.2E-02	5.8E-02	5.5E-02	5.4E-02	5.3E-02
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	-1.5E+00	-1.5E+00	-2.2E+00	-2.0E+00	-2.5E+00	-2.1E+00	-2.0E+00	-2.4E+00	-2.0E+00	-1.8E+00	-2.1E+00	-2.1E+00
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	-8.2E+00	-8.1E+00	-1.2E+01	-1.1E+01	-1.4E+01	-1.1E+01	-1.1E+01	-1.3E+01	-1.1E+01	-9.9E+00	-1.2E+01	-1.2E+01
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	-2.2E+00	-2.2E+00	-3.3E+00	-3.0E+00	-3.7E+00	-3.0E+00	-2.9E+00	-3.5E+00	-2.9E+00	-2.6E+00	-3.1E+00	-3.2E+00
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	-1.1E+01	-1.1E+01	-1.6E+01	-1.5E+01	-1.7E+01	-1.5E+01	-1.4E+01	-1.7E+01	-1.4E+01	-1.3E+01	-1.5E+01	-1.6E+01

Dolomite, in ground	7.7E-08	9.5E-08	8.0E-08	8.8E-08	1.4E-07	7.8E-08	8.2E-08	9.1E-08	7.9E-08	7.6E-08	1.0E-07	7.7E-08
Fluorine, 4.5% in apatite, 1% in crude ore, in ground	1.4E-04	4.5E-04	1.2E-04	1.7E-04	1.5E-04	1.2E-04	1.2E-04	1.2E-04	1.3E-04	-2.6E-02	1.6E-04	-8.4E-03
Fluorine, 4.5% in apatite, 3% in crude ore, in ground	-4.5E-03	-4.4E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.1E-03	-4.5E-03	-1.6E-02	-4.5E-03	-8.2E-03
Fluorspar, 92%, in ground	-3.9E-03	-1.6E-03	-6.2E-03	-5.0E-03	-6.6E-03	-5.6E-03	-5.3E-03	-6.4E-03	-5.3E-03	-1.8E-01	-5.4E-03	-6.4E-02
Gas, mine, off-gas, process, coal mining	-2.2E+03	-3.1E+03	-7.1E+03	-3.5E+03	-3.4E+03	-1.3E+04	-1.6E+04	-1.7E+04	-8.4E+03	-1.3E+04	-8.8E+03	-4.4E+03
Gas, natural, in ground	-4.5E+04	-1.3E+05	-5.8E+04	-1.2E+05	2.8E+05	-4.2E+04	-3.8E+04	-3.6E+04	1.5E+04	-4.8E+04	-7.1E+04	-5.0E+04
Gypsum, in ground	3.1E-03	3.0E-03	4.7E-03	2.1E-02	5.3E-03	4.2E-03	4.0E-03	4.8E-03	4.0E-03	3.1E-03	4.7E-03	4.2E-03
Iron, 46% in ore, 25% in crude ore, in ground	-2.3E-01	-2.9E-01	-3.5E-01	-3.3E-01	-4.7E-01	-3.3E-01	-3.1E-01	-3.5E-01	-3.2E-01	-2.5E-01	-3.3E-01	-3.3E-01
Kaolinite, 24% in crude ore, in ground	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.5E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.4E-03	-2.0E-03
Kieserite, 25% in crude ore, in ground	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01
Lanthanum, in crude ore, in ground	4.7E-18	4.7E-18	7.6E-18	6.6E-18	8.6E-18	6.8E-18	6.4E-18	7.9E-18	6.5E-18	4.3E-18	6.8E-18	6.7E-18
Lead (Pb, ore)	-4.1E+01	-4.2E+01	-4.5E+01	-4.9E+01	-5.8E+01	-4.7E+01	-4.6E+01	-5.0E+01	-6.3E+01	-4.1E+01	-6.2E+01	-4.7E+01
Magnesite, 60% in crude ore, in ground	-3.1E-07	4.2E-07	-3.3E-07	1.5E-07	1.3E-06	-3.3E-07	-1.7E-07	1.8E-07	-3.2E-07	-3.6E-07	1.4E-07	-2.9E-07
Magnesium, 0.13% in water	-6.0E-09	-6.1E-09	-6.1E-09	-6.1E-09	-6.6E-09	-6.2E-09	-6.2E-09	-6.2E-09	-6.0E-09	-6.2E-09	-7.1E-09	-6.0E-09
Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	1.2E-02	2.7E-02	2.0E-02	2.7E-02	2.8E-02	2.0E-02	2.2E-02	3.1E-02	1.6E-02	2.8E-02	2.6E-02	2.1E-02
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	-3.3E+00	-3.2E+00	-4.9E+00	-4.4E+00	-5.2E+00	-4.6E+00	-4.3E+00	-5.2E+00	-4.4E+00	-4.0E+00	-4.6E+00	-4.7E+00
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	-4.7E-01	-4.6E-01	-7.0E-01	-6.3E-01	-7.9E-01	-6.5E-01	-6.2E-01	-7.4E-01	-6.2E-01	-5.6E-01	-6.6E-01	-6.7E-01
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	9.7E+00	2.1E+01	1.6E+01	2.2E+01	2.2E+01	1.6E+01	1.8E+01	2.5E+01	1.3E+01	2.3E+01	2.1E+01	1.7E+01
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	-1.7E+00	-1.7E+00	-2.6E+00	-2.3E+00	-2.9E+00	-2.4E+00	-2.3E+00	-2.7E+00	-2.3E+00	-2.1E+00	-2.4E+00	-2.5E+00

Molybdenum, 0.11% in sulfide, Mo 0.41% and Cu 0.36% in crude ore, in ground	2.0E+01	4.3E+01	3.2E+01	4.4E+01	4.5E+01	3.3E+01	3.6E+01	5.0E+01	2.6E+01	4.6E+01	4.3E+01	3.5E+01
Neodymium, in ground	1.1E-26	1.1E-26	1.8E-26	1.6E-26	2.1E-26	1.7E-26	1.6E-26	1.9E-26	1.6E-26	1.2E-26	1.7E-26	1.7E-26
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	-2.0E-03	4.7E-03	-2.2E-03	-2.2E-03	-2.2E-03	-2.0E-03	-2.0E-03	-2.0E-03	-1.9E-03	-1.5E-02	-2.1E-03	-6.2E-03
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	1.5E-01	6.0E-01	3.4E-01	5.2E-01	6.6E-01	3.5E-01	4.2E-01	5.9E-01	3.1E-01	2.3E-01	4.3E-01	2.4E-01
Oil, crude, in ground	-9.1E+04	-9.5E+04	-1.2E+05	-1.8E+05	-1.5E+05	-1.2E+05	-1.1E+05	-1.2E+05	-1.2E+05	-9.3E+04	-1.6E+05	-1.1E+05
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-8.8E-04	-9.1E-04	-1.3E-03	-1.4E-03	-1.6E-03	-1.4E-03	-1.3E-03	-1.5E-03	-1.4E-03	-1.6E-03	-1.4E-03	-1.5E-03
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-2.1E-03	-2.2E-03	-3.2E-03	-3.4E-03	-3.9E-03	-3.3E-03	-3.0E-03	-3.7E-03	-3.4E-03	-3.7E-03	-3.4E-03	-3.5E-03
Phosphorus, 18% in apatite, 12% in crude ore, in ground	-5.1E-01	-4.9E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-4.7E-01	-5.1E-01	-1.8E+00	-5.1E-01	-9.4E-01
Phosphorus, 18% in apatite, 4% in crude ore, in ground	1.6E-02	5.1E-02	1.3E-02	1.9E-02	1.7E-02	1.4E-02	1.4E-02	1.3E-02	1.4E-02	-2.9E+00	1.8E-02	-9.6E-01
Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-3.9E-04	-4.2E-04	-4.5E-04	-4.6E-04	-5.3E-04	-4.4E-04	-4.3E-04	-4.6E-04	-4.3E-04	-4.3E-04	-4.9E-04	-4.4E-04
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-1.4E-03	-1.5E-03	-1.6E-03	-1.7E-03	-1.9E-03	-1.6E-03	-1.6E-03	-1.7E-03	-1.6E-03	-1.6E-03	-1.8E-03	-1.6E-03
Pyrite, in ground	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.3E-05	9.4E-05	9.3E-05	9.4E-05
Raw Materials (unspecified)	2.8E-17	3.5E-17	2.0E-17	5.0E-17	2.2E-17	1.9E-17	2.0E-17	1.5E-17	2.1E-17	2.0E-17	3.7E-17	2.8E-17
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-2.3E-03	-2.7E-03	-3.5E-03	-3.5E-03	-4.2E-03	-3.4E-03	-3.2E-03	-3.7E-03	-3.4E-03	-2.6E-03	-3.6E-03	-3.2E-03

Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-7.2E-03	-8.4E-03	-1.1E-02	-1.1E-02	-1.3E-02	-1.1E-02	-1.0E-02	-1.2E-02	-1.1E-02	-8.2E-03	-1.1E-02	-1.0E-02
Rhenium, in crude ore, in ground	-7.3E-05	-8.2E-05	-1.1E-04	-1.1E-04	-1.3E-04	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-8.8E-05	-1.2E-04	-1.0E-04
Silver, 0.01% in crude ore, in ground	-1.9E-01	-3.3E-02	-1.0E-01	-2.3E-01	-1.9E-01	-2.4E-01	-2.3E-01	-2.6E-01	-2.4E-01	-1.0E+00	-2.2E-01	-4.9E-01
Sodium chloride, in ground	-3.5E-03	-1.1E-03	-3.4E-03	-5.7E-03	-6.8E-03	-6.0E-03	-5.5E-03	-7.2E-03	-5.6E-03	-2.2E-02	-5.1E-03	-1.2E-02
sodium sulphate, various forms, in ground	-9.1E-03	6.4E-02	-1.0E-02	7.6E-04	-7.9E-04	-1.0E-02	-9.9E-03	-1.0E-02	-9.4E-03	-5.9E+00	-2.9E-03	-2.0E+00
Stibnite, in ground	-5.6E-05	-5.3E-05	-6.4E-05	-4.6E-05	-6.2E-05	-6.1E-05	-6.4E-05	-6.0E-05	-6.2E-05	-4.7E-05	-7.6E-05	-5.7E-05
Sulfur, in ground	-2.2E-01	-2.2E-01	-2.2E-01	-3.1E-01	-2.5E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.3E-01	-2.9E-01	-2.2E-01
sylvite, 25 % in sylvinite, in ground	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04
Talc, in ground	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.3E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.2E-04	-1.0E-04
Tin, 79% in cassiterite, 0.1% in crude ore, in ground	-9.6E-02	-5.5E-02	-6.7E-02	-1.1E-01	-1.0E-01	-1.2E-01	-1.1E-01	-1.2E-01	-1.2E-01	-3.3E-01	-1.2E-01	-1.8E-01
Ulexite, in ground	-2.9E-03	-3.0E-03	-3.0E-03	-3.0E-03	-3.6E-03	-3.1E-03	-3.1E-03	-3.2E-03	-3.1E-03	-3.4E-03	-3.5E-03	-3.1E-03
Uranium, in ground	-7.7E-01	-7.1E-01	-7.5E-01	-5.8E-01	-7.2E-01	-7.3E-01	-7.9E-01	-6.4E-01	-5.9E-01	-5.6E-01	-9.3E-01	-6.6E-01
Zinc (Zn, ore)	1.6E+02	1.6E+02	2.7E+02	2.3E+02	3.0E+02	2.4E+02	2.2E+02	2.8E+02	2.3E+02	1.6E+02	2.4E+02	2.4E+02
Zirconia, as baddeleyite, in ground	-6.3E-07	-2.6E-08	-3.1E-07	-7.5E-07	-6.1E-07	-8.0E-07	-7.7E-07	-8.9E-07	-8.1E-07	-3.7E-06	-7.5E-07	-1.7E-06

Table 41: France acidification impacts by pollutant (kg SO_2 equivalent)

Substances	Landfill	Incinerati	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-198501	-162499	-269315	-286792	-282253	-284334	-273245	-305385	-241590	-235425	-330340	-246753
Ammonia	292	5015	3984	3628	1265	1037	1255	396	5769	3050	6382	5346
Nitrogen oxides (NO and NO_2 as NO_2)	-28435	18270	-21812	-49425	-45021	281	22281	21068	-10369	19007	-43243	-27212
Sulfur dioxide	-158167	-179425	-218553	-229824	-225492	-197491	-189161	-216477	-185109	-180935	-211363	-203511
Sulphur oxides (SO_2 and SO_3 as SO_2)	-12192	-6359	-32934	-11171	-13004	-88161	-107619	-110372	-51881	-76546	-82116	-21377

Table 42: France eutrophication impacts by pollutant (kg PO_4 equivalents)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		1.7E+04	2.2E+03	1.3E+04	1.2E+04	1.5E+03	1.1E+03	4.0E+03	-1.5E+03	4.1E+03	1.1E+04	-6.3E+03	6.1E+03
Ammonia	air	6.4E+01	1.1E+03	8.7E+02	7.9E+02	2.8E+02	2.3E+02	2.8E+02	8.7E+01	1.3E+03	6.7E+02	1.4E+03	1.2E+03
Nitrate	air	5.2E-01	5.3E-01	5.0E-01	5.8E-01	6.6E-01	5.5E-01	5.4E-01	5.6E-01	7.9E-01	5.2E-01	7.7E-01	5.5E-01
Nitrogen oxides (NO and NO_2 as NO_2)	air	-7.4E+03	4.8E+03	-5.7E+03	-1.3E+04	-1.2E+04	7.3E+01	5.8E+03	5.5E+03	-2.7E+03	4.9E+03	-1.1E+04	-7.1E+03
Nitrous oxide	air	-1.9E+02	1.6E+03	-1.3E+02	-1.8E+02	-1.4E+02	2.4E+02	8.4E+01	7.5E+01	6.6E+01	-8.1E+02	4.9E+01	-2.6E+02
Phosphorus	air	-6.1E+01	-6.7E+01	-6.1E+01	-6.6E+01	-7.1E+01	-5.8E+01	-5.7E+01	-5.6E+01	-5.6E+01	-5.9E+01	-6.6E+01	-5.9E+01
Ammonia (NH_4^+, NH_3, as N)	water	3.0E+04	8.1E+02	2.6E+04	3.1E+04	2.2E+04	6.8E+03	5.1E+03	1.6E+03	1.7E+03	1.5E+04	3.6E+03	2.1E+04
Ammonium, ion	water	-5.9E+01	-3.9E+01	-6.9E+01	-6.7E+01	-6.4E+01	-7.2E+01	-7.4E+01	-7.6E+01	-6.7E+01	-1.1E+02	-6.7E+01	-8.0E+01
COD, Chemical Oxygen Demand	water	-2.8E+03	-3.1E+03	-3.7E+03	-2.3E+03	-3.9E+03	-3.2E+03	-3.2E+03	-3.6E+03	-3.3E+03	-2.9E+03	-2.5E+03	-3.4E+03
Nitrate	water	8.8E+02	8.6E+02	8.5E+02	8.5E+02	9.3E+02	8.7E+02	8.8E+02	8.7E+02	8.8E+02	8.7E+02	9.4E+02	8.6E+02
Nitrite	water	-2.8E-01	-2.6E-01	-3.1E-01	-2.9E-01	-2.2E-01	-3.1E-01	-3.1E-01	-3.2E-01	-2.8E-01	-4.8E-01	-2.3E-01	-3.8E-01
Nitrogen	water	1.5E+03	1.4E+03	1.4E+03	1.4E+03	1.3E+03	1.4E+03	1.5E+03	1.4E+03	1.3E+04	1.4E+03	8.2E+03	1.4E+03
Nitrogen - as total N	water	8.1E-01	4.5E-01	8.2E-01	7.9E-01	7.7E-01	8.0E-01	8.1E-01	8.0E-01	7.4E-01	8.2E-01	7.5E-01	8.1E-01
Phosphate	water	-3.9E+03	-4.2E+03	-5.9E+03	-5.4E+03	-6.5E+03	-5.6E+03	-5.4E+03	-6.4E+03	-5.4E+03	-6.3E+03	-5.7E+03	-6.2E+03
Phosphorus	water	-8.2E+02	-8.2E+02	-8.2E+02	-8.1E+02	-8.3E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.5E+02	-8.2E+02	-8.3E+02
Phosphorus - as total P	water	-9.7E-07	-9.5E-07	-9.7E-07	-9.7E-07	-9.7E-07	1.3E+03	-9.7E-07	-9.7E-07	-9.6E-07	-9.7E-07	-9.7E-07	-9.7E-07
Nitrogen	soil	2.0E-05	1.3E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05
Phosphorus	soil	-6.3E+01	-9.0E+01	-7.4E+01	-9.1E+01	-6.9E+01	-5.9E+01	-5.4E+01	-5.5E+01	-5.2E+01	-5.4E+01	-6.1E+01	-6.5E+01

Table 43: France human toxicity impacts by pollutant (kg 1,4-DCB equivalent)

Substances	Compartment	Landfill	Incinerati	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		-1.2E+08	-1.2E+08	-1.9E+08	-1.7E+08	-2.1E+08	-1.7E+08	-1.6E+08	-2.0E+08	-1.5E+08	-1.2E+08	-1.6E+08	-1.7E+08
Acenaphthene	air	-3.9E+01	-5.7E+01	-5.1E+01	-6.0E+01	-5.1E+01	-3.6E+01	-3.3E+01	-3.4E+01	-3.0E+01	-3.3E+01	-3.6E+01	-4.1E+01
Acrolein	air	-1.3E+00	-1.2E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00
Ammonia	air	1.8E+01	3.1E+02	2.5E+02	2.3E+02	7.9E+01	6.5E+01	7.8E+01	2.5E+01	3.6E+02	1.9E+02	4.0E+02	3.3E+02
Antimony	air	-2.7E+03	2.3E+04	-2.3E+03	-1.8E+03	-2.5E+03	-1.1E+03	-1.6E+03	-2.8E+03	-9.1E+02	-1.1E+03	-9.5E+02	-1.4E+03
Arsenic	air	-8.1E+05	-3.6E+05	-1.0E+06	-1.0E+06	-1.1E+06	-8.0E+05	-7.9E+05	-8.5E+05	-8.7E+05	-8.8E+05	-8.2E+05	-1.0E+06

Barium	air	-2.8E+03	-3.2E+03	-4.0E+03	-3.7E+03	-4.2E+03	-3.8E+03	-3.7E+03	-4.2E+03	-3.5E+03	-3.4E+03	-3.7E+03	-3.6E+03
Benzene	air	-1.7E+05	-2.6E+05	-2.1E+05	-2.2E+05	-2.3E+05	-1.7E+05	-1.7E+05	-2.0E+05	-1.5E+05	-1.5E+05	-1.7E+05	-1.7E+05
Benzene, ethyl-	air	-4.7E+00	-5.3E+00	-6.7E+00	1.2E+02	-7.9E+00	-6.3E+00	-5.9E+00	-6.8E+00	-6.3E+00	-4.8E+00	-6.8E+00	-6.0E+00
Benzene, pentachloro-	air	3.3E-01	1.6E-02	3.0E-01	1.7E-02	4.2E-01	5.1E-01	5.5E-01	6.0E-01	5.8E-01	4.9E-01	6.3E-01	4.0E-01
Beryllium	air	-4.1E+03	-4.3E+03	-5.0E+03	-4.6E+03	-4.5E+03	-5.2E+03	-5.4E+03	-5.6E+03	-4.8E+03	-5.3E+03	-4.5E+03	-4.6E+03
Butadiene [1,3-Butadiene]	air	1.3E+05	1.2E+05	1.3E+05	1.2E+05	1.1E+05	1.3E+05	1.3E+05	1.3E+05	1.0E+05	1.3E+05	1.1E+05	1.2E+05
Cadmium	air	-1.8E+05	-7.8E+04	-2.4E+05	-2.4E+05	-2.7E+05	-2.0E+05	-1.9E+05	-2.2E+05	-2.0E+05	-2.0E+05	-2.1E+05	-2.4E+05
Carbon disulphide	air	1.4E+02	1.8E+02	2.7E+02	2.5E+02	3.2E+02	2.3E+02	2.3E+02	3.1E+02	1.8E+02	1.5E+02	2.3E+02	2.3E+02
Carbon tetrachloride [Tetrachloromethane]	air	3.9E+01	8.9E+00	8.9E+01	3.3E+01	2.4E+01	1.5E+01	4.7E+00	2.0E+00	3.5E+00	-8.4E+01	1.3E+00	-1.4E+00
Chlorinated Matter (unspecified, as Cl)	air	-4.7E-06	-1.2E-07	-2.3E-06	-5.7E-06	-4.6E-06	-6.1E-06	-5.9E-06	-6.7E-06	-6.2E-06	-2.8E-05	-5.7E-06	-1.3E-05
Chloroform [Trichloromethane]	air	2.1E+00	-9.0E-03	1.2E+00	1.7E+00	1.3E+00	9.1E-01	3.5E-01	2.3E-01	3.1E-01	6.6E-01	1.8E-01	1.7E+00
Chromium VI	air	-2.1E+05	4.6E+04	1.1E+06	1.8E+06	2.1E+06	6.7E+05	7.0E+05	1.1E+06	1.7E+06	1.8E+06	1.7E+06	1.6E+06
Cobalt	air	-2.4E+04	-1.3E+04	-3.1E+04	-3.8E+04	-3.0E+04	-2.2E+04	-2.0E+04	-2.0E+04	-1.8E+04	-2.3E+04	-1.8E+04	-2.6E+04
Copper	air	-1.7E+05	-1.4E+05	-2.5E+05	-2.3E+05	-2.9E+05	-2.3E+05	-2.1E+05	-2.6E+05	-2.2E+05	-1.7E+05	-2.2E+05	-2.3E+05
Dichloromethane	air	2.7E-01	-1.7E-01	8.2E-02	1.9E-01	9.1E-02	2.1E-02	-9.2E-02	-1.2E-01	-1.0E-01	-2.7E-02	-1.3E-01	1.8E-01
Dioxins and furans- as ITEQ	air	3.2E+01	2.5E+04	2.6E+03	7.2E+01	7.4E+01	8.9E+03	1.1E+04	1.1E+04	4.2E+03	7.5E+03	8.0E+03	1.1E+03
Dioxins and furans- as WHO TEQ	air	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.5E+02	-2.4E+02	-2.4E+02	-2.4E+02
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.4E+05	-2.6E+05	-2.6E+05	-2.6E+05	-3.2E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-3.0E+05	-2.5E+05
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.8E+02	2.9E+00	4.9E+01	1.4E+02	6.5E+01	9.2E+01	5.1E+01	8.2E+01	8.6E+01	5.4E+01	1.7E+01	1.2E+02
Ethane, 1,2-dichloro-	air	-4.3E+01	-4.6E+01	-4.9E+01	-4.6E+01	-5.9E+01	-4.8E+01	-4.8E+01	-4.9E+01	-4.7E+01	-5.0E+01	-5.6E+01	-4.9E+01
Ethylene [Ethene]	air	1.5E+01	4.1E+00	-7.0E+00	-5.7E+00	3.2E+00	-8.5E+00	-8.0E+00	-1.4E+01	-5.4E+00	1.3E+00	1.4E+01	-3.7E+00
Ethylene oxide [1,2-Epoxyethane]	air	-1.6E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04
Formaldehyde [Methanal]	air	-9.1E+01	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.1E+02	-1.0E+02	-1.1E+02	-1.0E+02	-9.4E+01	-1.0E+02	-1.1E+02
Hexachlorobenzene	air	2.1E+02	7.1E+02	8.1E+01	2.1E+02	3.7E+03	6.6E+02	1.1E+03	1.9E+03	9.4E+02	5.0E+02	2.0E+03	2.4E+02
Hydrocarbons (unspecified)	air	-5.6E-01	9.2E+00	-5.4E-01	-6.9E-01	-8.3E-01	-6.2E-01	-6.0E-01	-6.4E-01	-1.1E+00	-5.6E-01	-1.0E+00	-6.2E-01
Hydrogen chloride	air	-8.5E+02	3.3E+02	-7.8E+02	-1.1E+03	6.8E+02	-3.8E+02	-2.8E+02	-3.4E+02	-5.3E+02	-4.0E+02	-8.7E+02	-7.6E+02
Hydrogen fluoride	air	-4.2E+06	-4.8E+06	-6.9E+06	-6.1E+06	-7.6E+06	-6.2E+06	-5.9E+06	-7.3E+06	-6.0E+06	-4.5E+06	-6.4E+06	-6.1E+06
Hydrogen sulfide	air	-1.2E+02	-1.4E+02	-1.2E+02	-1.2E+02	-2.5E+01	-1.2E+02	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02
Lead	air	-4.0E+02	-8.6E+02	1.8E+03	2.5E+02	6.6E+02	1.4E+03	1.4E+03	2.7E+03	9.6E+02	-8.1E+02	1.5E+03	5.8E+02
Mercury	air	-5.8E+03	7.2E+03	-4.3E+03	-5.3E+03	-3.2E+03	-2.8E+03	-2.9E+03	-3.1E+03	-2.8E+03	-1.1E+03	-2.9E+03	-4.5E+03

Methyl bromide [Bromomethane]	air	2.2E-06	2.2E-06	3.5E-06	3.0E-06	3.9E-06	3.1E-06	2.9E-06	3.6E-06	3.0E-06	2.1E-06	3.1E-06	3.1E-06
Molybdenum	air	-1.9E+03	-2.8E+03	-2.7E+03	-3.3E+03	-2.5E+03	-2.1E+03	-1.9E+03	-2.1E+03	-1.7E+03	-2.2E+03	-1.6E+03	-2.4E+03
m-Xylene	air	-2.2E-01	-2.4E-01	-2.3E-01	-2.4E-01	-2.7E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.5E-01	-2.2E-01
Nickel	air	-8.3E+05	-4.9E+05	-1.1E+06	-1.1E+06	-1.1E+06	-9.4E+05	-8.6E+05	-1.0E+06	-8.4E+05	-7.9E+05	-8.1E+05	-9.9E+05
Nitrogen oxides (NO and NO_2 as NO_2)	air	-6.8E+04	4.4E+04	-5.2E+04	-1.2E+05	-1.1E+05	6.7E+02	5.3E+04	5.1E+04	-2.5E+04	4.6E+04	-1.0E+05	-6.5E+04
o-Xylene	air			1.1E+01		1.1E+01	4.5E+01	2.0E+01	2.0E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01
PAH, polycyclic aromatic hydrocarbons	air	-1.1E+08	-1.1E+08	-1.7E+08	-1.5E+08	-1.9E+08	-1.5E+08	-1.4E+08	-1.8E+08	-1.5E+08	-1.0E+08	-1.5E+08	-1.5E+08
Particulates, < 2.5 um	air	-1.5E+04	-1.6E+04	-2.1E+04	-2.0E+04	-2.4E+04	-1.9E+04	-1.9E+04	-2.1E+04	-1.9E+04	-1.6E+04	-2.0E+04	-2.0E+04
Particulates, > 2.5 um, and < 10um	air	-2.1E+04	-2.3E+04	-3.2E+04	-3.0E+04	-3.8E+04	-2.9E+04	-2.8E+04	-3.3E+04	-2.8E+04	-2.2E+04	-3.0E+04	-3.0E+04
Pentachlorophenol	air	-4.1E-01	1.3E-01	-4.4E-01	-4.3E-01	-5.2E-01	-4.5E-01	-4.5E-01	-4.7E-01	-4.4E-01	-4.8E-01	-5.1E-01	-4.5E-01
Phenol	air	8.4E-01	1.3E+00	1.1E+00	8.4E-01	1.2E+00	8.5E-01	8.6E-01	8.2E-01	8.6E-01	7.7E-01	1.2E+00	8.1E-01
Propylene oxide	air	4.3E+02	4.3E+02	4.0E+02	4.0E+02	5.0E+02	7.4E+02	7.8E+02	3.9E+02	4.9E+02	3.9E+02	3.9E+02	3.9E+02
Selenium	air	-1.0E+05	-1.2E+05	-1.4E+05	-1.4E+05	-1.5E+05	-1.2E+05	-1.2E+05	-1.3E+05	-1.1E+05	-1.1E+05	-1.2E+05	-1.3E+05
Sodium dichromate	air	-6.3E+03	-1.5E+04	-2.4E+05	-1.6E+05	-2.2E+05	-1.8E+05	-1.4E+05	-2.6E+05	-1.5E+05	-1.2E+04	-9.7E+04	-1.8E+05
Styrene	air	-1.0E-03	-8.9E-04	1.7E+00	1.6E+00	1.6E+00	5.3E+00	1.8E+00	1.9E+00	2.4E+00	2.5E+00	2.6E+00	2.3E+00
Sulfur dioxide	air	-1.3E+04	-1.4E+04	-1.7E+04	-1.8E+04	-1.8E+04	-1.6E+04	-1.5E+04	-1.7E+04	-1.5E+04	-1.4E+04	-1.7E+04	-1.6E+04
Sulphur oxides (SO_2 and SO_3 as SO_2)	air	-9.8E+02	-5.1E+02	-2.6E+03	-8.9E+02	-1.0E+03	-7.1E+03	-8.6E+03	-8.8E+03	-4.2E+03	-6.1E+03	-6.6E+03	-1.7E+03
Tetrachloroethylene	air	1.0E+00	-8.8E-02	5.5E-01	8.1E-01	5.7E-01	3.9E-01	1.1E-01	3.7E-02	7.5E-02	2.7E-01	2.2E-02	8.1E-01
Thallium	air	-6.0E+03	-6.2E+03	1.3E+05	1.3E+05	1.3E+05	6.2E+04	6.1E+04	6.1E+04	1.8E+05	1.8E+05	1.8E+05	1.9E+05
Tin	air	-6.6E-01	1.0E+01	-9.6E-01	-8.8E-01	-1.0E+00	-8.7E-01	-8.1E-01	-9.1E-01	-8.4E-01	-7.8E-01	-8.7E-01	-9.3E-01
Toluene	air	-8.3E+00	-2.2E+01	6.4E+01	3.8E+01	3.7E+01	2.0E+02	1.5E+02	1.5E+02	1.1E+02	1.4E+02	1.5E+02	7.4E+01
Trichloroethylene	air	8.7E+01	1.0E+00	5.0E+01	7.1E+01	5.2E+01	3.8E+01	1.6E+01	1.1E+01	1.4E+01	2.9E+01	9.5E+00	7.0E+01
Vanadium	air	-2.0E+05	-2.4E+05	-2.5E+05	-2.8E+05	-2.4E+05	-2.1E+05	-2.0E+05	-2.1E+05	-1.9E+05	-2.6E+05	-1.8E+05	-2.4E+05
Vinyl chloride	air	-5.6E+01	-6.9E+01	-9.9E+01	-8.4E+01	-1.1E+02	-9.1E+01	-8.9E+01	-1.1E+02	-9.0E+01	-6.8E+01	-9.7E+01	-8.7E+01
Zinc	air	2.6E+04	2.6E+04	4.3E+04	3.7E+04	4.9E+04	3.9E+04	3.6E+04	4.5E+04	3.7E+04	2.6E+04	3.9E+04	3.8E+04
Acenaphthene	water	-1.8E+02	-2.1E+02	-3.1E+02	-3.1E+02	-3.8E+02	-2.9E+02	-2.7E+02	-3.3E+02	-3.0E+02	-1.9E+02	-3.1E+02	-2.7E+02
Acenaphthylene	water	-5.4E-01	-9.6E+00	-7.3E+00	-1.3E+01	-2.3E+01	-1.0E+01	-7.7E+00	-1.3E+01	-2.8E+01	-1.2E+00	-2.5E+01	-8.4E+00
Antimony	water	-1.3E+05	-4.9E+04	-1.4E+05	-3.4E+05	-1.7E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.3E+05	-1.7E+05	-1.4E+05
Arsenic	water	4.6E+04	1.7E+03	3.5E+04	4.4E+04	3.7E+04	1.4E+04	1.7E+04	3.7E+03	1.2E+04	1.8E+04	1.8E+04	2.1E+04
Arsenic, ion	water	-1.2E+05	-1.2E+05	-1.9E+05	-1.7E+05	-2.1E+05	-1.7E+05	-1.6E+05	-2.0E+05	-1.6E+05	-1.3E+05	-1.7E+05	-1.7E+05

Barite	water	-2.9E+05	-7.7E+05	-5.0E+05	-6.5E+05	5.8E+05	-2.9E+05	-2.3E+05	-2.6E+05	-7.3E+04	-2.1E+05	-2.8E+05	-3.4E+05
Barium	water	-2.1E+05	2.8E+04	-3.1E+05	-3.2E+05	-3.5E+05	-2.7E+05	-2.6E+05	-3.0E+05	-2.6E+05	-2.2E+05	-1.1E+05	-2.8E+05
Benzene	water	-4.5E+04	-4.6E+04	-5.5E+04	-5.4E+04	-6.6E+04	-5.3E+04	-5.1E+04	-5.6E+04	-5.4E+04	-4.6E+04	-6.1E+04	-5.2E+04
Benzene, chloro-	water	-2.7E-01	-2.3E-02	-1.4E-01	-3.2E-01	-2.6E-01	-3.4E-01	-3.3E-01	-3.7E-01	-3.4E-01	-1.5E+00	-3.1E-01	-7.2E-01
Beryllium	water	-3.9E+04	-4.1E+04	-5.6E+04	-5.0E+04	-6.3E+04	-5.2E+04	-5.0E+04	-5.8E+04	-4.9E+04	-4.4E+04	-2.9E+04	-5.2E+04
Cadmium	water	8.5E+01	2.3E+02	2.5E+01	4.8E+01	3.8E+01	1.4E+01	7.3E+00	-5.0E-01	6.8E+00	1.2E+01	6.1E+01	3.4E+01
Cadmium, ion	water	-1.1E+02	-1.2E+02	-1.1E+02	-1.3E+02	-1.3E+02	-1.1E+02	-1.1E+02	-1.1E+02	-1.6E+02	-1.5E+02	-1.5E+02	-1.3E+02
Chlorinated solvents, unspecified	water	-8.2E-01	-6.7E-01	-9.3E-01	-1.4E+00	-1.4E+00	-1.1E+00	-1.1E+00	-1.3E+00	-1.1E+00	-1.8E+00	-1.3E+00	-1.5E+00
Chloroform [Trichloromethane]	water	-7.0E-04	4.9E-05	-2.9E-04	-8.6E-04	-6.9E-04	-9.3E-04	-8.9E-04	-1.0E-03	-9.5E-04	-4.6E-03	-8.6E-04	-2.1E-03
Chromium	water	1.4E+02	8.1E+01	5.7E+01	1.1E+02	7.5E+01	5.6E+01	4.1E+01	4.3E+01	5.5E+01	3.8E+01	1.1E+02	6.5E+01
Chromium VI	water	-3.0E+03	-3.0E+03	-4.9E+03	-4.4E+03	-5.4E+03	-4.4E+03	-4.1E+03	-5.1E+03	-4.2E+03	-3.2E+03	-4.4E+03	-4.4E+03
Cobalt	water	-2.0E+03	-1.5E+03	-3.0E+03	-2.4E+03	-3.0E+03	-2.7E+03	-2.4E+03	-2.9E+03	-2.5E+03	-2.1E+03	1.5E+03	-2.8E+03
Copper	water	8.7E+01	3.7E+02	1.6E+01	5.7E+01	2.2E+01	5.4E+01	2.7E+01	3.9E+01	4.8E+01	4.5E+01	1.0E+02	5.5E+01
Copper, ion	water	6.0E+02	-1.3E+02	4.6E+02	-1.6E+02	7.0E+02	9.3E+02	1.0E+03	1.1E+03	1.1E+03	9.2E+02	1.2E+03	6.9E+02
Di(2-ethylhexyl)phthalate (DEHP)	water	3.5E+01	8.0E-01	1.6E+01	1.9E+01	2.0E+01	7.7E+00	4.6E+00	3.8E+00	3.7E+00	9.3E+00	4.6E+00	2.2E+01
Dichloromethane	water	-1.8E+00	-2.9E+00	-3.4E+00	-3.3E+00	-8.8E-01	-3.2E+00	-2.9E+00	-3.6E+00	-2.8E+00	-2.0E+00	-3.3E+00	-2.9E+00
Dichromate	water	-2.9E+00	-3.0E+00	-4.5E+00	-4.0E+00	-5.1E+00	-4.1E+00	-3.9E+00	-4.7E+00	-3.9E+00	-2.9E+00	-4.1E+00	-4.1E+00
Ethane, 1,1,1-trichloro-, HCFC-140	water	-7.2E-07	-8.5E-07	-7.0E-07	-8.3E-07	-9.6E-07	-7.7E-07	-7.5E-07	-7.9E-07	-1.2E-06	-7.2E-07	-1.1E-06	-7.7E-07
Ethene	water	-4.9E+00	-5.0E+00	-5.1E+00	-5.0E+00	-6.2E+00	-5.1E+00	-5.0E+00	-5.1E+00	-5.0E+00	-5.0E+00	-6.0E+00	-5.0E+00
Ethene, chloro-	water	-1.4E+00	-1.4E+00	-2.2E+00	-1.9E+00	-2.4E+00	-1.9E+00	-1.8E+00	-2.3E+00	-1.9E+00	-1.4E+00	-2.0E+00	-2.0E+00
Ethene, tetrachloro-	water	4.2E-07	3.6E-07	4.4E-07	4.1E-07	3.9E-07	4.1E-07	4.2E-07	4.1E-07	3.6E-07	4.2E-07	3.9E-07	4.2E-07
Ethene, trichloro-	water	3.7E-01	8.2E-03	1.8E-01	3.4E-01	2.8E-01	1.1E-01	8.5E-02	7.6E-02	9.5E-02	1.5E-01	4.7E-02	2.0E-01
Ethylbenzene	water	-1.8E+00	-2.2E+00	-3.3E+00	-3.2E+00	-3.9E+00	-3.1E+00	-2.8E+00	-3.5E+00	-3.2E+00	-2.0E+00	-3.3E+00	-2.8E+00
Ethylene dichloride	water	-3.0E+02	-3.0E+02	-3.0E+02	-2.9E+02	-3.6E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.3E+02	-3.5E+02	-3.1E+02
Ethylene oxide	water	-5.2E+02	-5.1E+02	-5.1E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.4E+02	-5.2E+02	-5.3E+02
Formaldehyde	water	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-6.0E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-5.9E-01	-4.9E-01
Fungicides, unspecified	water	8.5E-03	8.5E-03	8.5E-03	8.5E-03	1.0E-02	8.5E-03	8.5E-03	8.5E-03	8.5E-03	8.4E-03	1.0E-02	8.4E-03
Herbicides, unspecified	water	-3.9E-06	-1.1E-07	-1.9E-06	-4.7E-06	-3.8E-06	-5.1E-06	-4.9E-06	-5.6E-06	-5.1E-06	-2.3E-05	-4.7E-06	-1.1E-05
Insecticides, unspecified	water	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Lead	water	7.5E+02	-8.9E+02	-1.2E+02	-1.2E+03	2.1E+02	1.5E+03	1.0E+03	1.1E+03	1.1E+03	8.1E+02	3.6E+03	4.2E+02

Mercury	water	-3.6E+02	-1.0E+03	-5.6E+02	-5.2E+02	-5.9E+02	-6.2E+02	-5.2E+02	-5.7E+02	-6.1E+02	-6.9E+02	1.4E+02	-7.0E+02
Metals (unspecified)	water	-5.9E-01	-5.8E-01	-5.7E-01	-5.9E-01	-5.8E-01	-5.9E-01	-5.9E-01	-5.9E-01	-6.0E-01	-5.9E-01	-5.9E-01	-5.9E-01
Molybdenum	water	-9.0E+04	3.8E+05	-1.1E+05	-1.0E+05	-1.2E+05	-1.0E+05	-1.0E+05	-1.1E+05	-9.4E+04	-9.2E+04	-1.1E+05	-1.0E+05
m-Xylene	water	6.2E-03	6.1E-03	6.4E-03	6.3E-03	6.3E-03	6.3E-03	6.3E-03	6.4E-03	6.1E-03	6.2E-03	6.2E-03	6.3E-03
Nickel	water	2.5E+04	7.3E+03	1.1E+04	2.0E+04	1.1E+04	1.5E+04	1.2E+04	1.1E+04	1.4E+04	1.5E+04	6.9E+04	1.5E+04
Nickel, ion	water	-6.7E+03	-1.4E+04	-1.2E+04	-2.1E+04	-1.6E+02	-1.5E+03	2.5E+03	4.8E+03	2.5E+03	-5.0E+03	4.3E+03	-9.0E+03
o-Xylene	water	2.9E-04	2.9E-04	4.6E-04	4.0E-04	5.2E-04	4.2E-04	3.9E-04	4.8E-04	4.0E-04	2.9E-04	4.2E-04	4.1E-04
PAH, polycyclic aromatic hydrocarbons	water	-1.6E+05	-1.8E+05	-2.8E+05	-2.7E+05	-3.3E+05	-2.6E+05	-2.3E+05	-2.8E+05	-2.7E+05	-1.6E+05	-2.7E+05	-2.4E+05
Phenol	water	-5.4E-01	-6.7E-01	-8.9E-01	-1.1E+00	-1.1E+00	-8.6E-01	-8.1E-01	-9.8E-01	-9.0E-01	-6.0E-01	-1.1E+00	-7.9E-01
Phthalate, dibutyl-	water	1.4E-08	4.4E-09	1.6E-08	8.5E-09	8.4E-10	1.1E-08	1.2E-08	1.0E-08	-1.1E-08	1.4E-08	-6.7E-09	1.1E-08
Propylene oxide	water	1.7E+03	1.7E+03	1.6E+03	1.6E+03	2.0E+03	3.0E+03	3.1E+03	1.6E+03	2.0E+03	1.6E+03	1.6E+03	1.6E+03
Selenium	water	-1.0E+06	-1.0E+06	-1.6E+06	-1.4E+06	-1.8E+06	-1.5E+06	-1.4E+06	-1.7E+06	-1.4E+06	-1.1E+06	-1.3E+06	-1.5E+06
Thallium	water	-4.1E+04	-5.3E+04	-7.7E+04	-7.5E+04	-8.0E+04	-6.3E+04	-5.8E+04	-7.3E+04	-5.4E+04	-4.9E+04	-5.7E+04	-6.5E+04
Tin, ion	water	3.8E-01	-7.4E-02	2.3E-01	-1.6E-01	3.9E-01	5.4E-01	6.2E-01	6.3E-01	6.6E-01	5.6E-01	1.1E+00	3.9E-01
Toluene	water	-3.4E+00	-4.2E+00	-6.2E+00	-6.1E+00	-7.4E+00	-5.9E+00	-5.4E+00	-6.7E+00	-6.1E+00	-3.7E+00	-6.2E+00	-5.3E+00
Tributyltin compounds	water	-2.2E+03	-2.4E+03	-3.4E+03	-3.1E+03	-3.9E+03	-3.0E+03	-2.9E+03	-3.4E+03	-2.9E+03	-2.3E+03	-3.1E+03	-3.1E+03
Vanadium, ion	water	-4.3E+06	-4.3E+06	-7.1E+06	-6.2E+06	-8.0E+06	-6.3E+06	-6.0E+06	-7.4E+06	-6.0E+06	-4.5E+06	-6.4E+06	-6.4E+06
Xylene - all isomers [Dimethylbenzene]	water	-3.9E+00	-4.8E+00	-7.2E+00	-7.0E+00	-8.6E+00	-6.7E+00	-6.2E+00	-7.7E+00	-7.0E+00	-4.3E+00	-7.2E+00	-6.1E+00
Zinc	water	6.7E+02	-2.5E+02	3.3E+01	2.8E+02	3.0E+02	4.4E+02	1.8E+02	2.3E+02	3.4E+02	2.7E+02	1.6E+03	3.0E+02
2,4-D	soil	5.3E+01	5.3E+01	5.2E+01	5.3E+01	6.5E+01	5.2E+01	5.3E+01	5.2E+01	5.3E+01	5.2E+01	6.3E+01	5.2E+01
Antimony	soil	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.9E-01	8.1E-01	8.4E-01	8.3E-01
Arsenic	soil	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.0E+06	3.4E+05	1.9E+06	3.4E+05
Atrazine	soil	-6.4E-04	-5.8E-04	-6.3E-04	-7.3E-04	-7.9E-04	-7.0E-04	-6.9E-04	-7.2E-04	-9.6E-04	-1.0E-03	-9.4E-04	-8.1E-04
Barium	soil	-7.7E+03	-1.2E+04	-1.4E+04	-1.4E+04	-3.8E+03	-1.3E+04	-1.2E+04	-1.5E+04	-1.2E+04	-8.6E+03	-1.4E+04	-1.2E+04
Bentazone	soil	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.4E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.3E+00	1.9E+00
Cadmium	soil	8.3E+03	8.2E+03	8.2E+03	8.2E+03	8.2E+03	8.3E+03	8.3E+03	8.3E+03	1.3E+05	8.3E+03	8.3E+04	8.3E+03
Chlorothalonil	soil	5.5E+01	5.5E+01	5.4E+01	5.5E+01	5.4E+01	5.4E+01	5.4E+01	5.4E+01	5.5E+01	5.5E+01	5.4E+01	5.4E+01
Chromium	soil	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.4E+06	1.5E+05	9.3E+05	1.5E+05
Chromium VI	soil	-1.1E+05	-1.1E+05	-1.7E+05	-1.5E+05	-1.9E+05	-1.5E+05	-1.5E+05	-1.8E+05	-1.5E+05	-1.1E+05	-1.6E+05	-1.5E+05
Cobalt	soil	-2.2E+01	-3.0E+01	-2.3E+01	-3.0E+01	-2.6E+01	-1.8E+01	-1.7E+01	-1.6E+01	-1.6E+01	-1.9E+01	-1.9E+01	-2.1E+01

Copper	soil	-7.8E+03	-7.8E+03	-8.1E+03	-8.0E+03	-8.3E+03	-8.0E+03	-8.0E+03	-8.2E+03	5.4E+04	-7.8E+03	3.0E+04	-8.0E+03
Cypermethrin	soil	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03
Dinoseb	soil	-1.3E-01	-1.4E-01	-3.4E-01	-1.8E-01	-1.8E-01	-1.7E-01	-1.7E-01	-1.8E-01	-2.1E-01	-1.6E-01	-3.1E-01	-1.4E-01
Glyphosate	soil	5.9E-02	5.9E-02	5.8E-02	5.9E-02	7.2E-02	5.8E-02	5.8E-02	5.8E-02	5.9E-02	5.8E-02	7.0E-02	5.8E-02
Lead	soil	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.0E+06	5.9E+05	3.3E+06	5.9E+05
Linuron	soil	3.2E+02	3.2E+02	3.2E+02	3.2E+02	4.0E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.8E+02	3.2E+02
Mercury	soil	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.8E+04	1.9E+03	1.2E+04	1.9E+03
Metazachlor	soil	1.3E+02	7.2E+01	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.2E+02	1.3E+02
Metolachlor	soil	1.6E+02	1.6E+02	1.6E+02	1.6E+02	2.0E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.9E+02	1.6E+02
Molybdenum	soil	-2.7E+01	-3.7E+01	-2.9E+01	-3.8E+01	-3.2E+01	-2.3E+01	-2.1E+01	-2.1E+01	-2.0E+01	-2.6E+01	-2.4E+01	-2.7E+01
Nickel	soil	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	5.5E+05	6.3E+04	3.6E+05	6.3E+04
Pirimicarb	soil	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.9E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.7E-01	3.1E-01
Selenium	soil	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03
Thallium	soil	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.1E-03	8.2E-03	8.1E-03	8.2E-03
Tin	soil	-5.0E-04	1.0E-03	-5.2E-04	-2.0E-03	-2.7E-03	-2.2E-03	-1.9E-03	-3.1E-03	-1.9E-03	-1.3E-02	-1.5E-03	-6.4E-03
Vanadium	soil	-4.3E+02	-6.1E+02	-4.7E+02	-6.0E+02	-5.1E+02	-3.6E+02	-3.3E+02	-3.2E+02	-3.2E+02	-3.6E+02	-3.8E+02	-4.1E+02
Zinc	soil	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.7E+05	1.5E+04	1.1E+05	1.5E+04

Table 44: France freshwater ecotoxicity impacts (kg 1,4-DCB equivalents)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		-9.6E+06	-1.0E+07	-1.6E+07	-1.4E+07	-1.8E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.0E+07	-9.9E+06	-1.1E+07	-1.4E+07
Acenaphthene	air	-1.2E-02	-1.7E-02	-1.5E-02	-1.8E-02	-1.5E-02	-1.1E-02	-9.8E-03	-1.0E-02	-9.0E-03	-9.7E-03	-1.1E-02	-1.2E-02
Acrolein	air	-1.2E+01	-1.1E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01
Antimony	air	-1.5E+00	1.3E+01	-1.3E+00	-9.8E-01	-1.4E+00	-6.1E-01	-8.9E-01	-1.6E+00	-5.1E-01	-6.4E-01	-5.3E-01	-7.9E-01
Arsenic	air	-1.2E+02	-5.1E+01	-1.4E+02	-1.5E+02	-1.6E+02	-1.1E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.3E+02	-1.2E+02	-1.5E+02
Barium	air	-1.6E+02	-1.8E+02	-2.3E+02	-2.1E+02	-2.4E+02	-2.1E+02	-2.1E+02	-2.4E+02	-2.0E+02	-1.9E+02	-2.1E+02	-2.1E+02
Benzene	air	-7.3E-03	-1.1E-02	-9.3E-03	-9.6E-03	-1.0E-02	-7.7E-03	-7.5E-03	-8.6E-03	-6.7E-03	-6.4E-03	-7.4E-03	-7.6E-03
Benzene, ethyl-	air	-6.3E-04	-7.1E-04	-9.0E-04	1.6E-02	-1.1E-03	-8.4E-04	-7.9E-04	-9.2E-04	-8.6E-04	-6.5E-04	-9.2E-04	-8.1E-04
Benzene, pentachloro-	air	3.0E-04	1.5E-05	2.7E-04	1.5E-05	3.8E-04	4.6E-04	5.0E-04	5.4E-04	5.2E-04	4.4E-04	5.7E-04	3.6E-04

Benzo(a)pyrene	air	-5.1E+02	-4.9E+02	-8.3E+02	-7.2E+02	-9.3E+02	-7.4E+02	-7.0E+02	-8.7E+02	-7.1E+02	-5.2E+02	-7.5E+02	-7.4E+02
Beryllium	air	-3.1E+02	-3.2E+02	-3.7E+02	-3.5E+02	-3.4E+02	-4.0E+02	-4.1E+02	-4.2E+02	-3.6E+02	-4.0E+02	-3.4E+02	-3.5E+02
Butadiene [1,3-Butadiene]	air	1.9E-05	1.8E-05	1.9E-05	1.8E-05	1.6E-05	1.9E-05	2.0E-05	1.9E-05	1.5E-05	2.0E-05	1.6E-05	1.8E-05
Cadmium	air	-3.5E+02	-1.6E+02	-4.8E+02	-4.7E+02	-5.4E+02	-4.0E+02	-3.8E+02	-4.5E+02	-4.0E+02	-4.0E+02	-4.3E+02	-4.7E+02
Carbon disulphide	air	1.9E+00	2.4E+00	3.7E+00	3.3E+00	4.4E+00	3.2E+00	3.1E+00	4.2E+00	2.5E+00	2.0E+00	3.1E+00	3.1E+00
Carbon tetrachloride [Tetrachloromethane]	air	4.4E-05	1.0E-05	1.0E-04	3.8E-05	2.7E-05	1.7E-05	5.3E-06	2.3E-06	4.0E-06	-9.6E-05	1.4E-06	-1.6E-06
Chlorinated Matter (unspecified, as Cl)	air	-2.7E-11	-6.9E-13	-1.3E-11	-3.3E-11	-2.6E-11	-3.5E-11	-3.4E-11	-3.9E-11	-3.5E-11	-1.6E-10	-3.2E-11	-7.6E-11
Chloroform [Trichloromethane]	air	1.6E-05	-6.8E-08	9.1E-06	1.3E-05	9.5E-06	6.9E-06	2.7E-06	1.8E-06	2.3E-06	5.0E-06	1.4E-06	1.3E-05
Chromium VI	air	-4.7E-01	1.0E-01	2.6E+00	4.1E+00	4.8E+00	1.5E+00	1.6E+00	2.4E+00	3.9E+00	4.0E+00	3.8E+00	3.6E+00
Cobalt	air	-9.0E+02	-4.6E+02	-1.1E+03	-1.4E+03	-1.1E+03	-7.9E+02	-7.1E+02	-7.2E+02	-6.5E+02	-8.3E+02	-6.6E+02	-9.7E+02
Copper	air	-8.7E+03	-7.5E+03	-1.3E+04	-1.2E+04	-1.5E+04	-1.2E+04	-1.1E+04	-1.3E+04	-1.1E+04	-8.8E+03	-1.2E+04	-1.2E+04
Dichloromethane	air	4.5E-06	-2.8E-06	1.4E-06	3.1E-06	1.5E-06	3.5E-07	-1.6E-06	-2.0E-06	-1.8E-06	-4.6E-07	-2.1E-06	3.1E-06
Dioxins and furans- as ITEQ	air	3.5E-02	2.7E+01	2.9E+00	7.9E-02	8.2E-02	9.7E+00	1.2E+01	1.2E+01	4.7E+00	8.3E+00	8.8E+00	1.2E+00
Dioxins and furans- as WHO TEQ	air	-2.6E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.7E-01	-2.6E-01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.7E+02	-2.9E+02	-2.8E+02	-2.9E+02	-3.5E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.7E+02	-3.3E+02	-2.8E+02
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.3E-03	2.1E-05	3.6E-04	1.0E-03	4.8E-04	6.8E-04	3.8E-04	6.1E-04	6.4E-04	4.0E-04	1.2E-04	9.2E-04
Ethane, 1,2-dichloro-	air	-7.5E-04	-8.0E-04	-8.6E-04	-8.1E-04	-1.0E-03	-8.3E-04	-8.3E-04	-8.6E-04	-8.3E-04	-8.7E-04	-9.8E-04	-8.5E-04
Ethylene [Ethene]	air	3.3E-10	9.1E-11	-1.6E-10	-1.3E-10	7.2E-11	-1.9E-10	-1.8E-10	-3.2E-10	-1.2E-10	3.0E-11	3.1E-10	-8.2E-11
Ethylene oxide [1,2-Epoxyethane]	air	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01
Formaldehyde [Methanal]	air	-9.1E+02	-1.1E+03	-1.2E+03	-1.2E+03	-1.2E+03	-1.1E+03	-1.0E+03	-1.1E+03	-1.0E+03	-9.3E+02	-1.0E+03	-1.1E+03
Hexachlorobenzene	air	8.9E-05	3.0E-04	3.4E-05	9.1E-05	1.6E-03	2.8E-04	4.7E-04	8.1E-04	4.0E-04	2.1E-04	8.2E-04	1.0E-04
Hydrocarbons (unspecified)	air	-3.0E-10	4.8E-09	-2.8E-10	-3.6E-10	-4.4E-10	-3.3E-10	-3.2E-10	-3.4E-10	-5.7E-10	-3.0E-10	-5.4E-10	-3.2E-10
Hydrogen fluoride	air	-6.8E+03	-7.9E+03	-1.1E+04	-9.9E+03	-1.2E+04	-1.0E+04	-9.7E+03	-1.2E+04	-9.8E+03	-7.3E+03	-1.0E+04	-9.9E+03
Lead	air	-2.1E+00	-4.4E+00	9.2E+00	1.3E+00	3.4E+00	7.4E+00	7.2E+00	1.4E+01	4.9E+00	-4.2E+00	7.9E+00	3.0E+00
Mercury	air	-3.0E+02	3.8E+02	-2.3E+02	-2.8E+02	-1.7E+02	-1.5E+02	-1.6E+02	-1.7E+02	-1.5E+02	-5.8E+01	-1.5E+02	-2.4E+02
Methyl bromide [Bromomethane]	air	2.0E-10	2.0E-10	3.2E-10	2.8E-10	3.6E-10	2.9E-10	2.7E-10	3.4E-10	2.8E-10	2.0E-10	2.9E-10	2.9E-10
Molybdenum	air	-3.5E+01	-5.0E+01	-4.9E+01	-5.8E+01	-4.4E+01	-3.7E+01	-3.4E+01	-3.8E+01	-3.1E+01	-3.9E+01	-2.9E+01	-4.3E+01
m-Xylene	air	-3.6E-04	-3.9E-04	-3.6E-04	-3.9E-04	-4.3E-04	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-4.0E-04	-3.5E-04
Nickel	air	-1.5E+04	-8.8E+03	-1.9E+04	-1.9E+04	-2.0E+04	-1.7E+04	-1.5E+04	-1.9E+04	-1.5E+04	-1.4E+04	-1.4E+04	-1.8E+04
o-Xylene	air			8.2E-03		8.2E-03	3.4E-02	1.5E-02	1.5E-02	1.2E-02	1.2E-02	1.2E-02	1.2E-02

PAH, polycyclic aromatic hydrocarbons	air	-3.2E+04	-3.2E+04	-5.2E+04	-4.5E+04	-5.8E+04	-4.6E+04	-4.3E+04	-5.4E+04	-4.4E+04	-3.1E+04	-4.6E+04	-4.6E+04
Pentachlorophenol	air	-8.5E-01	2.7E-01	-9.1E-01	-8.9E-01	-1.1E+00	-9.3E-01	-9.4E-01	-9.6E-01	-9.1E-01	-1.0E+00	-1.1E+00	-9.3E-01
Phenol	air	2.5E+00	3.7E+00	3.1E+00	2.4E+00	3.5E+00	2.5E+00	2.5E+00	2.4E+00	2.5E+00	2.2E+00	3.4E+00	2.4E+00
Propylene oxide	air	1.3E-02	1.3E-02	1.2E-02	1.2E-02	1.5E-02	2.2E-02	2.3E-02	1.1E-02	1.4E-02	1.1E-02	1.1E-02	1.1E-02
Selenium	air	-1.2E+03	-1.4E+03	-1.6E+03	-1.6E+03	-1.7E+03	-1.4E+03	-1.3E+03	-1.5E+03	-1.3E+03	-1.2E+03	-1.4E+03	-1.5E+03
Sodium dichromate	air	-1.4E-02	-3.3E-02	-5.3E-01	-3.6E-01	-4.9E-01	-3.9E-01	-3.2E-01	-5.9E-01	-3.4E-01	-2.8E-02	-2.2E-01	-3.9E-01
Styrene	air	-1.1E-06	-9.5E-07	1.8E-03	1.7E-03	1.7E-03	5.7E-03	2.0E-03	2.0E-03	2.6E-03	2.7E-03	2.7E-03	2.5E-03
Tetrachloroethylene	air	7.7E-05	-6.6E-06	4.1E-05	6.1E-05	4.3E-05	2.9E-05	7.9E-06	2.8E-06	5.6E-06	2.0E-05	1.6E-06	6.0E-05
Thallium	air	-2.2E+01	-2.2E+01	4.6E+02	4.6E+02	4.6E+02	2.2E+02	2.2E+02	2.2E+02	6.6E+02	6.5E+02	6.6E+02	6.7E+02
Tin	air	-9.6E-01	1.5E+01	-1.4E+00	-1.3E+00	-1.5E+00	-1.3E+00	-1.2E+00	-1.3E+00	-1.2E+00	-1.1E+00	-1.3E+00	-1.4E+00
Toluene	air	-1.8E-03	-4.7E-03	1.4E-02	8.1E-03	7.9E-03	4.3E-02	3.3E-02	3.3E-02	2.3E-02	3.1E-02	3.1E-02	1.6E-02
Trichloroethylene	air	9.7E-05	1.2E-06	5.6E-05	7.8E-05	5.8E-05	4.2E-05	1.8E-05	1.2E-05	1.5E-05	3.2E-05	1.1E-05	7.8E-05
Vanadium	air	-5.5E+04	-6.6E+04	-6.9E+04	-7.8E+04	-6.6E+04	-5.8E+04	-5.5E+04	-5.9E+04	-5.2E+04	-7.1E+04	-5.0E+04	-6.8E+04
Vinyl chloride	air	-1.9E-06	-2.3E-06	-3.4E-06	-2.8E-06	-3.8E-06	-3.1E-06	-3.0E-06	-3.7E-06	-3.1E-06	-2.3E-06	-3.3E-06	-3.0E-06
Zinc	air	4.4E+03	4.4E+03	7.4E+03	6.3E+03	8.3E+03	6.6E+03	6.2E+03	7.7E+03	6.3E+03	4.4E+03	6.6E+03	6.5E+03
Acenaphthene	water	-1.7E+01	-2.0E+01	-3.0E+01	-3.0E+01	-3.6E+01	-2.8E+01	-2.6E+01	-3.2E+01	-2.9E+01	-1.8E+01	-3.0E+01	-2.6E+01
Acenaphthylene	water	-5.2E-02	-9.3E-01	-7.1E-01	-1.3E+00	-2.2E+00	-9.7E-01	-7.5E-01	-1.3E+00	-2.7E+00	-1.2E-01	-2.4E+00	-8.1E-01
Antimony	water	-3.8E+02	-1.5E+02	-4.3E+02	-1.0E+03	-5.1E+02	-3.7E+02	-3.6E+02	-3.7E+02	-3.5E+02	-4.0E+02	-5.2E+02	-4.1E+02
Arsenic	water	6.1E+03	2.3E+02	4.7E+03	5.8E+03	4.9E+03	1.9E+03	2.3E+03	5.0E+02	1.7E+03	2.5E+03	2.4E+03	2.7E+03
Arsenic, ion	water	-1.6E+04	-1.6E+04	-2.5E+04	-2.2E+04	-2.8E+04	-2.3E+04	-2.2E+04	-2.6E+04	-2.2E+04	-1.7E+04	-2.3E+04	-2.3E+04
Barite	water	-8.5E+04	-2.3E+05	-1.5E+05	-1.9E+05	1.7E+05	-8.5E+04	-6.8E+04	-7.6E+04	-2.2E+04	-6.3E+04	-8.2E+04	-1.0E+05
Barium	water	-6.2E+04	8.3E+03	-9.2E+04	-9.5E+04	-1.0E+05	-8.2E+04	-7.7E+04	-8.9E+04	-7.8E+04	-6.6E+04	-3.4E+04	-8.2E+04
Benzene	water	-2.2E+00	-2.3E+00	-2.7E+00	-2.6E+00	-3.2E+00	-2.6E+00	-2.5E+00	-2.7E+00	-2.6E+00	-2.2E+00	-2.9E+00	-2.5E+00
Benzene, chloro-	water	-9.2E-03	-8.1E-04	-4.7E-03	-1.1E-02	-9.0E-03	-1.2E-02	-1.1E-02	-1.3E-02	-1.2E-02	-5.2E-02	-1.1E-02	-2.5E-02
Beryllium	water	-2.1E+05	-2.2E+05	-3.1E+05	-2.7E+05	-3.5E+05	-2.9E+05	-2.8E+05	-3.2E+05	-2.7E+05	-2.4E+05	-1.6E+05	-2.8E+05
Cadmium	water	3.2E+03	8.5E+03	9.5E+02	1.8E+03	1.4E+03	5.4E+02	2.8E+02	-1.9E+01	2.6E+02	4.7E+02	2.3E+03	1.3E+03
Cadmium, ion	water	-4.0E+03	-4.4E+03	-4.0E+03	-5.1E+03	-5.0E+03	-4.3E+03	-4.2E+03	-4.3E+03	-6.0E+03	-5.5E+03	-5.7E+03	-4.8E+03
Chlorinated solvents, unspecified	water	-8.7E-02	-7.1E-02	-9.8E-02	-1.5E-01	-1.4E-01	-1.2E-01	-1.1E-01	-1.4E-01	-1.2E-01	-1.9E-01	-1.4E-01	-1.5E-01
Chloroform [Trichloromethane]	water	-2.1E-06	1.5E-07	-8.8E-07	-2.6E-06	-2.1E-06	-2.8E-06	-2.7E-06	-3.1E-06	-2.9E-06	-1.4E-05	-2.6E-06	-6.4E-06
Chromium	water	2.6E+02	1.5E+02	1.1E+02	2.1E+02	1.4E+02	1.0E+02	7.7E+01	8.0E+01	1.0E+02	7.1E+01	2.0E+02	1.2E+02

Chromium VI	water	-1.4E+04	-1.3E+04	-2.2E+04	-1.9E+04	-2.4E+04	-2.0E+04	-1.8E+04	-2.3E+04	-1.9E+04	-1.4E+04	-2.0E+04	-2.0E+04
Cobalt	water	-6.3E+04	-4.9E+04	-9.6E+04	-7.7E+04	-9.6E+04	-8.5E+04	-7.8E+04	-9.2E+04	-8.1E+04	-6.8E+04	4.9E+04	-9.0E+04
Copper	water	4.3E+04	1.8E+05	8.2E+03	2.9E+04	1.1E+04	2.7E+04	1.4E+04	1.9E+04	2.4E+04	2.2E+04	5.1E+04	2.8E+04
Copper, ion	water	3.0E+05	-6.3E+04	2.3E+05	-7.9E+04	3.5E+05	4.6E+05	5.2E+05	5.5E+05	5.4E+05	4.6E+05	5.9E+05	3.4E+05
Di(2-ethylhexyl)phthalate (DEHP)	water	1.5E+01	3.3E-01	6.5E+00	8.0E+00	8.2E+00	3.2E+00	1.9E+00	1.6E+00	1.5E+00	3.9E+00	1.9E+00	8.9E+00
Dichloromethane	water	-1.2E-02	-1.8E-02	-2.2E-02	-2.1E-02	-5.7E-03	-2.0E-02	-1.8E-02	-2.3E-02	-1.8E-02	-1.3E-02	-2.1E-02	-1.9E-02
Dichromate	water	-1.3E+01	-1.3E+01	-2.0E+01	-1.8E+01	-2.3E+01	-1.8E+01	-1.7E+01	-2.1E+01	-1.7E+01	-1.3E+01	-1.8E+01	-1.8E+01
Ethane, 1,1,1-trichloro-, HCFC-140	water	-4.2E-09	-5.0E-09	-4.1E-09	-4.9E-09	-5.6E-09	-4.5E-09	-4.4E-09	-4.6E-09	-6.9E-09	-4.2E-09	-6.7E-09	-4.5E-09
Ethene	water	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.1E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.0E-01	-1.7E-01
Ethene, chloro-	water	-2.4E-04	-2.5E-04	-3.9E-04	-3.4E-04	-4.4E-04	-3.5E-04	-3.3E-04	-4.0E-04	-3.3E-04	-2.6E-04	-3.5E-04	-3.5E-04
Ethene, tetrachloro-	water	4.6E-08	3.9E-08	4.8E-08	4.5E-08	4.2E-08	4.5E-08	4.5E-08	4.5E-08	3.9E-08	4.6E-08	4.2E-08	4.5E-08
Ethene, trichloro-	water	9.6E-04	2.2E-05	4.8E-04	8.9E-04	7.3E-04	2.8E-04	2.2E-04	2.0E-04	2.5E-04	4.0E-04	1.2E-04	5.3E-04
Ethylbenzene	water	-1.2E+00	-1.4E+00	-2.1E+00	-2.1E+00	-2.5E+00	-2.0E+00	-1.8E+00	-2.3E+00	-2.1E+00	-1.3E+00	-2.1E+00	-1.8E+00
Ethylene dichloride	water	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.9E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.6E-01	-2.8E-01	-2.4E-01
Ethylene oxide	water	-4.4E-01	-4.3E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.6E-01	-4.4E-01	-4.5E-01
Formaldehyde	water	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.5E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.4E+03	-3.7E+03
Fungicides, unspecified	water	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.7E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.5E-03	4.6E-03
Herbicides, unspecified	water	-3.4E-05	-9.4E-07	-1.6E-05	-4.1E-05	-3.3E-05	-4.4E-05	-4.2E-05	-4.8E-05	-4.4E-05	-2.0E-04	-4.1E-05	-9.5E-05
Insecticides, unspecified	water	8.7E+00	8.7E+00	8.7E+00	8.7E+00	1.1E+01	8.7E+00	8.7E+00	8.7E+00	8.7E+00	8.6E+00	1.0E+01	8.7E+00
Lead	water	2.8E+02	-3.4E+02	-4.5E+01	-4.5E+02	7.9E+01	5.7E+02	4.0E+02	4.1E+02	4.1E+02	3.1E+02	1.4E+03	1.6E+02
Mercury	water	-2.2E+02	-6.2E+02	-3.4E+02	-3.2E+02	-3.6E+02	-3.8E+02	-3.2E+02	-3.5E+02	-3.7E+02	-4.2E+02	8.6E+01	-4.3E+02
Metals (unspecified)	water	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02
Molybdenum	water	-6.4E+03	2.7E+04	-7.9E+03	-7.4E+03	-8.6E+03	-7.4E+03	-7.3E+03	-7.7E+03	-6.7E+03	-6.6E+03	-8.0E+03	-7.3E+03
m-Xylene	water	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02
Nickel	water	1.7E+05	5.2E+04	7.6E+04	1.4E+05	7.5E+04	1.0E+05	8.3E+04	7.9E+04	9.6E+04	1.1E+05	4.9E+05	1.1E+05
Nickel, ion	water	-4.8E+04	-9.7E+04	-8.7E+04	-1.5E+05	-1.1E+03	-1.1E+04	1.8E+04	3.4E+04	1.8E+04	-3.5E+04	3.1E+04	-6.4E+04
o-Xylene	water	3.8E-04	3.8E-04	6.1E-04	5.3E-04	6.9E-04	5.5E-04	5.1E-04	6.3E-04	5.2E-04	3.8E-04	5.5E-04	5.4E-04
PAH, polycyclic aromatic hydrocarbons	water	-1.5E+04	-1.7E+04	-2.6E+04	-2.6E+04	-3.1E+04	-2.5E+04	-2.2E+04	-2.7E+04	-2.6E+04	-1.5E+04	-2.6E+04	-2.3E+04
Phenol	water	-2.6E+03	-3.2E+03	-4.3E+03	-5.2E+03	-5.2E+03	-4.1E+03	-3.9E+03	-4.7E+03	-4.3E+03	-2.9E+03	-5.1E+03	-3.8E+03
Phthalate, dibutyl-	water	2.1E-06	6.5E-07	2.4E-06	1.3E-06	1.2E-07	1.6E-06	1.8E-06	1.5E-06	-1.7E-06	2.0E-06	-9.8E-07	1.7E-06

Propylene oxide	water	2.6E+00	2.6E+00	2.4E+00	2.4E+00	3.0E+00	4.5E+00	4.7E+00	2.3E+00	2.9E+00	2.3E+00	2.4E+00	2.4E+00
Selenium	water	-4.5E+04	-4.6E+04	-7.1E+04	-6.2E+04	-8.0E+04	-6.4E+04	-6.1E+04	-7.4E+04	-6.1E+04	-4.6E+04	-5.9E+04	-6.4E+04
Thallium	water	-1.2E+03	-1.6E+03	-2.2E+03	-2.2E+03	-2.3E+03	-1.8E+03	-1.7E+03	-2.1E+03	-1.6E+03	-1.4E+03	-1.7E+03	-1.9E+03
Tin, ion	water	1.1E+02	-2.2E+01	6.8E+01	-4.5E+01	1.1E+02	1.6E+02	1.8E+02	1.8E+02	1.9E+02	1.6E+02	3.3E+02	1.2E+02
Toluene	water	-3.2E+00	-3.9E+00	-5.9E+00	-5.7E+00	-7.0E+00	-5.5E+00	-5.1E+00	-6.3E+00	-5.7E+00	-3.5E+00	-5.9E+00	-5.0E+00
Tributyltin compounds	water	-2.9E+05	-3.2E+05	-4.5E+05	-4.2E+05	-5.2E+05	-4.0E+05	-3.8E+05	-4.5E+05	-3.9E+05	-3.0E+05	-4.1E+05	-4.1E+05
Vanadium, ion	water	-9.3E+06	-9.3E+06	-1.5E+07	-1.3E+07	-1.7E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.3E+07	-9.7E+06	-1.4E+07	-1.4E+07
Xylene - all isomers [Dimethylbenzene]	water	-5.2E+00	-6.4E+00	-9.6E+00	-9.3E+00	-1.1E+01	-9.0E+00	-8.2E+00	-1.0E+01	-9.3E+00	-5.7E+00	-9.5E+00	-8.2E+00
Zinc	water	5.5E+04	-2.1E+04	2.7E+03	2.3E+04	2.5E+04	3.6E+04	1.5E+04	1.9E+04	2.8E+04	2.2E+04	1.3E+05	2.5E+04
2,4-D	soil	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.1E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.0E+01	3.3E+01
Antimony	soil	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.1E-03	1.9E-03	2.0E-03	2.0E-03
Arsenic	soil	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	4.6E+04	5.2E+03	3.0E+04	5.2E+03
Atrazine	soil	-1.0E-02	-9.3E-03	-1.0E-02	-1.2E-02	-1.3E-02	-1.1E-02	-1.1E-02	-1.2E-02	-1.6E-02	-1.7E-02	-1.5E-02	-1.3E-02
Barium	soil	-2.7E+03	-4.2E+03	-5.0E+03	-4.9E+03	-1.3E+03	-4.7E+03	-4.2E+03	-5.3E+03	-4.1E+03	-3.0E+03	-4.9E+03	-4.3E+03
Bentazone	soil	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Cadmium	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	2.0E+04	1.3E+03	1.3E+04	1.3E+03
Chlorothalonil	soil	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01
Chromium	soil	5.3E+02	5.3E+02	5.3E+02	5.3E+02	5.4E+02	5.3E+02	5.3E+02	5.3E+02	5.0E+03	5.3E+02	3.2E+03	5.3E+02
Chromium VI	soil	-9.1E+02	-9.3E+02	-1.4E+03	-1.2E+03	-1.6E+03	-1.3E+03	-1.2E+03	-1.5E+03	-1.2E+03	-9.2E+02	-1.3E+03	-1.3E+03
Cobalt	soil	-5.8E+01	-8.1E+01	-6.2E+01	-8.0E+01	-6.8E+01	-4.8E+01	-4.5E+01	-4.3E+01	-4.3E+01	-5.0E+01	-5.0E+01	-5.6E+01
Copper	soil	-1.9E+05	-1.9E+05	-2.0E+05	-2.0E+05	-2.0E+05	-2.0E+05	-1.9E+05	-2.0E+05	1.3E+06	-1.9E+05	7.2E+05	-2.0E+05
Cypermethrin	soil	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.4E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.3E+05	1.1E+05
Dinoseb	soil	-4.8E+00	-4.9E+00	-1.2E+01	-6.5E+00	-6.3E+00	-6.0E+00	-6.2E+00	-6.4E+00	-7.4E+00	-5.8E+00	-1.1E+01	-5.1E+00
Glyphosate	soil	1.8E+01	1.8E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01
Lead	soil	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.2E+04	3.7E+03	2.1E+04	3.7E+03
Linuron	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03
Mercury	soil	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	6.8E+03	7.2E+02	4.4E+03	7.2E+02
Metazachlor	soil	1.0E+01	5.7E+00	1.0E+01	1.0E+01	9.9E+00	1.0E+01	1.0E+01	1.0E+01	9.4E+00	1.0E+01	9.5E+00	1.0E+01
Metolachlor	soil	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.2E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.1E+04	2.6E+04
Molybdenum	soil	-1.8E+00	-2.5E+00	-2.0E+00	-2.6E+00	-2.2E+00	-1.6E+00	-1.5E+00	-1.4E+00	-1.4E+00	-1.8E+00	-1.6E+00	-1.9E+00

Nickel	soil	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.1E+06	1.3E+05	7.4E+05	1.3E+05
Pirimicarb	soil	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.5E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.4E+01	2.0E+01
Selenium	soil	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04
Thallium	soil	5.8E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.7E-05	5.8E-05
Tin	soil	-9.3E-04	2.0E-03	-9.8E-04	-3.8E-03	-5.0E-03	-4.2E-03	-3.6E-03	-5.8E-03	-3.5E-03	-2.5E-02	-2.8E-03	-1.2E-02
Vanadium	soil	-3.4E+02	-4.8E+02	-3.7E+02	-4.8E+02	-4.0E+02	-2.8E+02	-2.6E+02	-2.5E+02	-2.5E+02	-2.8E+02	-3.0E+02	-3.3E+02
Zinc	soil	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	5.1E+05	4.5E+04	3.3E+05	4.5E+04

Table 45: Lithuania GHG emissions by pollutant (kg CO_2 equivalent)

Substances	Landfill	Incineration	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-1.5E+07	-3.6E+07	-3.6E+07	-4.5E+07	-4.2E+07	-4.2E+07	-4.8E+07	-5.7E+07	-3.8E+07	-3.5E+07	-6.0E+07	-2.8E+07
Carbon dioxide (CO_2)	4.9E+04	4.9E+04	4.9E+04	5.3E+04	6.0E+04	4.9E+04	4.9E+04	4.9E+04	4.9E+04	4.8E+04	6.0E+04	4.9E+04
Carbon dioxide, fossil	-3.7E+07	-3.1E+07	-4.8E+07	-6.3E+07	-5.3E+07	-3.6E+07	-3.4E+07	-3.8E+07	-2.6E+07	-2.9E+07	-5.0E+07	-4.2E+07
Carbon Monoxide (CO)	5.3E+04	-1.7E+03	4.1E+04	5.3E+04	3.4E+04	6.5E+03	1.2E+04	5.1E+02	-3.1E+02	2.0E+04	5.4E+03	3.7E+04
Carbon monoxide, biogenic	-3.0E+05	-3.0E+05	-4.9E+05	-4.3E+05	-5.5E+05	-4.4E+05	-4.1E+05	-5.1E+05	-4.2E+05	-3.0E+05	-4.4E+05	-4.4E+05
Carbon monoxide, fossil	-1.4E+05	-1.7E+05	-2.0E+05	-2.5E+05	-2.5E+05	-1.9E+05	-1.8E+05	-2.0E+05	-1.9E+05	-1.5E+05	-2.2E+05	-1.9E+05
Carbon tetrachloride [Tetrachloromethane]	2.5E+02	5.8E+01	5.7E+02	2.1E+02	1.5E+02	9.6E+01	3.0E+01	1.3E+01	2.2E+01	-5.3E+02	7.9E+00	-8.3E+00
Chlorinated Matter (unspecified, as Cl)	-8.2E-05	-1.9E-06	-3.9E-05	-9.9E-05	-8.0E-05	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-4.9E-04	-9.8E-05	-2.3E-04
Dichloromethane	1.2E+00	-7.4E-01	3.6E-01	8.2E-01	4.0E-01	9.3E-02	-4.1E-01	-5.2E-01	-4.6E-01	-1.2E-01	-5.5E-01	8.1E-01
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-3.0E+01	-2.8E+01	-9.4E+00	-2.0E+01	-2.9E+01	-2.6E+01	-2.7E+01	-2.2E+01	-3.0E+01	-2.0E+01	-2.8E+01	-2.6E+01
Ethane, 1,1,1-trichloro-, HCFC-140	1.6E+03	2.6E+01	4.3E+02	1.2E+03	5.7E+02	8.2E+02	4.5E+02	7.3E+02	7.6E+02	4.8E+02	1.5E+02	1.1E+03
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2.6E+04	4.4E+02	6.3E+03	1.9E+04	1.0E+04	1.2E+04	7.1E+03	1.1E+04	1.2E+04	7.8E+03	2.6E+03	1.7E+04
Ethane, 1,1-difluoro-, HFC-152a	-7.5E-01	-7.8E-01	-8.2E-01	-7.9E-01	-9.5E-01	-8.5E-01	-8.6E-01	-8.9E-01	-8.1E-01	-9.4E-01	-9.3E-01	-8.4E-01
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	3.0E+04	-1.2E+03	6.1E+03	2.3E+04	1.1E+04	1.4E+04	6.9E+03	1.2E+04	1.3E+04	8.6E+03	1.0E+03	2.0E+04
Ethane, 1-chloro-1,1-difluoro-, HCFC-142	2.1E+03	3.5E+01	5.9E+02	1.6E+03	7.8E+02	1.1E+03	6.2E+02	9.8E+02	1.0E+03	6.5E+02	2.0E+02	1.5E+03
Ethane, 2,2-dichloro-1,1,1-tri-fluoro-, HCFC-123	2.2E+01	3.7E-01	5.4E+00	1.6E+01	8.6E+00	1.1E+01	6.0E+00	9.0E+00	9.8E+00	6.7E+00	2.2E+00	1.4E+01
Ethane, 2-chloro-1,1,1,2-tetra-fluoro-, HCFC-124	8.3E+01	1.3E+00	2.3E+01	6.3E+01	3.0E+01	4.3E+01	2.4E+01	3.8E+01	4.0E+01	2.5E+01	7.8E+00	5.8E+01
Hydrocarbons (unspecified)	-1.0E+02	1.7E+03	-9.9E+01	-1.3E+02	-1.5E+02	-1.2E+02	-1.1E+02	-1.2E+02	-2.0E+02	-1.0E+02	-1.9E+02	-1.1E+02

Methane, (unspecified)	2.9E+07	5.4E+05	2.4E+07	2.7E+07	2.1E+07	1.1E+07	3.7E+06	1.5E+06	1.2E+06	9.8E+06	3.7E+06	2.4E+07
Methane, biogenic	9.4E+03	9.3E+03	3.4E+04	2.7E+04	4.0E+04	7.1E+04	4.5E+04	4.5E+04	8.7E+03	4.1E+04	4.4E+04	4.3E+04
Methane, bromochlorodifluoro-, Halon 1211	5.5E+01	-3.6E+02	1.8E+01	-2.6E+01	1.8E+03	6.7E+01	7.9E+01	9.2E+01	3.5E+02	2.8E+01	9.2E+01	3.3E+01
Methane, bromotrifluoro-, Halon 1301	-7.2E+02	-1.0E+03	-1.2E+03	-1.4E+03	-1.3E+03	-9.1E+02	-7.9E+02	-9.6E+02	-8.7E+02	-6.0E+02	-8.9E+02	-9.4E+02
Methane, chlorodifluoro-, HCFC-22	2.9E+03	-1.0E+03	7.3E+02	2.0E+03	6.8E+03	1.6E+03	9.4E+02	1.5E+03	2.4E+03	8.0E+02	4.1E+02	2.0E+03
Methane, chlorotrifluoro-, CFC-13	1.1E+04	1.9E+02	2.8E+03	8.4E+03	4.5E+03	5.5E+03	3.1E+03	4.7E+03	5.1E+03	3.5E+03	1.1E+03	7.5E+03
Methane, dichlorodifluoro-, CFC-12	6.7E+04	1.1E+03	1.9E+04	5.1E+04	2.5E+04	3.5E+04	1.9E+04	3.1E+04	3.3E+04	2.0E+04	6.4E+03	4.7E+04
Methane, fossil	-2.4E+06	-3.0E+06	-5.9E+06	-4.2E+06	-1.2E+06	-1.0E+07	-1.3E+07	-1.4E+07	-6.9E+06	-1.0E+07	-8.3E+06	-4.1E+06
Methane, tetrafluoro-, FC-14	-3.8E+06	-3.8E+06	-6.3E+06	-5.5E+06	-7.1E+06	-5.6E+06	-5.3E+06	-6.6E+06	-5.4E+06	-3.8E+06	-5.6E+06	-5.6E+06
Methane, trichlorofluoro-, CFC-11	1.5E+03	2.6E+01	3.7E+02	1.1E+03	5.9E+02	7.2E+02	4.1E+02	6.2E+02	6.7E+02	4.6E+02	1.5E+02	9.9E+02
Methane, trifluoro-, HFC-23	-1.2E+00	-4.3E-01	-8.0E-01	-1.3E+00	-1.2E+00	-1.5E+00	-1.4E+00	-1.6E+00	-1.4E+00	-5.1E+00	-1.4E+00	-2.6E+00
Methyl bromide [Bromomethane]	3.1E-08	3.1E-08	4.9E-08	4.3E-08	5.6E-08	4.4E-08	4.2E-08	5.1E-08	4.2E-08	3.0E-08	4.5E-08	4.4E-08
Methyl chloride [Chloromethane]	3.1E+00	1.8E-01	1.8E+00	2.5E+00	1.9E+00	1.4E+00	6.7E-01	5.0E-01	5.9E-01	1.1E+00	4.5E-01	2.5E+00
Nitrous oxide	-2.0E+05	1.8E+06	-1.2E+05	-1.7E+05	-1.4E+05	2.6E+05	9.2E+04	8.0E+04	7.0E+04	-8.9E+05	5.2E+04	-2.7E+05
Sulphur hexafluoride	-5.0E+04	-5.1E+04	-5.4E+04	-5.3E+04	-6.4E+04	-5.3E+04	-5.3E+04	-5.5E+04	-5.3E+04	-5.5E+04	-6.1E+04	-5.4E+04

Table 46: Lithuania abiotic resource depletion by pollutant (kg antimony equivalents)

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-3.4E+05	-5.0E+05	-6.4E+05	-6.1E+05	-1.8E+05	-8.5E+05	-9.8E+05	-1.1E+06	-5.9E+05	-8.1E+05	-7.4E+05	-4.8E+05
Aluminium, 24% in bauxite, 11% in crude ore, in ground	-2.4E-02	-2.4E-02	-4.0E-02	-3.4E-02	-4.4E-02	-3.5E-02	-3.3E-02	-4.1E-02	-3.4E-02	-2.4E-02	-3.6E-02	-3.5E-02
Anhydrite, in ground	-1.6E-03	-1.6E-03	-1.6E-03	-3.5E-03	-1.9E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-2.9E-03	-1.6E-03
Barite, 15% in crude ore, in ground	-7.1E-01	-1.5E+00	-1.2E+00	-1.5E+00	-3.3E-01	-7.9E-01	-6.5E-01	-7.7E-01	-5.6E-01	-5.7E-01	-7.3E-01	-9.0E-01
Borax, in ground	1.6E-03	1.7E-01	1.3E-01	5.3E-03	1.8E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-02	1.6E-03
Calcite, in ground	-2.5E-04	1.9E-04	-4.1E-04	-4.0E-04	-4.8E-04	-3.5E-04	-3.2E-04	-3.6E-04	-3.4E-04	-3.6E-04	-3.3E-04	-3.2E-04
Cerium, in ground	7.2E-18	7.1E-18	1.2E-17	1.0E-17	1.4E-17	1.1E-17	1.0E-17	1.2E-17	1.0E-17	7.5E-18	1.1E-17	1.1E-17
Chromium, 25.5 in chromite, 11.6% in crude ore, in ground	1.4E-01	1.0E+00	4.4E-01	7.3E-01	9.0E-01	4.7E-01	5.8E-01	7.3E-01	4.8E-01	-2.7E-01	4.1E-01	2.4E-02
Chrysotile, in ground	-3.3E-09	-1.7E-09	-7.0E-09	-5.8E-09	-7.2E-09	-6.1E-09	-5.6E-09	-7.4E-09	-5.7E-09	-1.3E-08	-5.1E-09	-9.3E-09
Cinnabar, in ground	-1.4E-01	-7.1E-02	-8.8E-02	-2.3E-01	-2.8E-01	-2.4E-01	-2.2E-01	-3.0E-01	-2.3E-01	-5.2E-01	-2.1E-01	-3.7E-01
Coal (in ground)	-9.5E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.4E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03	-9.5E+03

Coal, brown, in ground	-3.3E+04	-3.4E+04	-4.3E+04	-4.0E+04	-4.9E+04	-4.2E+04	-4.1E+04	-4.6E+04	-4.0E+04	-3.8E+04	-4.4E+04	-4.2E+04
Coal, hard, unspecified, in ground	-1.2E+05	-1.3E+05	-3.5E+05	-1.6E+05	-2.1E+05	-6.2E+05	-7.7E+05	-8.3E+05	-4.3E+05	-6.1E+05	-4.5E+05	-2.4E+05
Cobalt, in ground	9.6E-08	-3.6E-08	-2.7E-07	-3.1E-07	-5.3E-07	-3.0E-07	-2.3E-07	-5.6E-07	-5.4E-07	2.3E-08	-5.2E-07	-2.2E-07
Colemanite, in ground	5.6E-02	5.7E-02	5.3E-02	5.4E-02	5.2E-02	5.4E-02	5.4E-02	5.2E-02	5.8E-02	5.5E-02	5.4E-02	5.3E-02
Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	-1.5E+00	-1.5E+00	-2.2E+00	-2.0E+00	-2.5E+00	-2.1E+00	-2.0E+00	-2.4E+00	-2.0E+00	-1.8E+00	-2.1E+00	-2.1E+00
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	-8.2E+00	-8.2E+00	-1.2E+01	-1.1E+01	-1.4E+01	-1.1E+01	-1.1E+01	-1.3E+01	-1.1E+01	-9.9E+00	-1.2E+01	-1.2E+01
Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	-2.2E+00	-2.2E+00	-3.3E+00	-3.0E+00	-3.7E+00	-3.0E+00	-2.9E+00	-3.5E+00	-2.9E+00	-2.6E+00	-3.1E+00	-3.2E+00
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	-1.1E+01	-1.1E+01	-1.6E+01	-1.5E+01	-1.7E+01	-1.5E+01	-1.4E+01	-1.7E+01	-1.4E+01	-1.3E+01	-1.5E+01	-1.6E+01
Dolomite, in ground	7.6E-08	9.1E-08	7.8E-08	8.5E-08	1.4E-07	7.8E-08	8.2E-08	9.1E-08	7.9E-08	7.6E-08	1.0E-07	7.6E-08
Fluorine, 4.5% in apatite, 1% in crude ore, in ground	1.3E-04	4.3E-04	1.1E-04	1.5E-04	1.4E-04	1.2E-04	1.2E-04	1.2E-04	1.3E-04	-2.6E-02	1.6E-04	-8.4E-03
Fluorine, 4.5% in apatite, 3% in crude ore, in ground	-4.5E-03	-4.4E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.5E-03	-4.1E-03	-4.5E-03	-1.6E-02	-4.5E-03	-8.2E-03
Fluorspar, 92%, in ground	-3.9E-03	-1.8E-03	-6.3E-03	-5.2E-03	-6.7E-03	-5.6E-03	-5.3E-03	-6.4E-03	-5.2E-03	-1.8E-01	-5.4E-03	-6.4E-02
Gas, mine, off-gas, process, coal mining	-1.8E+03	-1.9E+03	-6.5E+03	-2.3E+03	-2.9E+03	-1.3E+04	-1.6E+04	-1.7E+04	-8.5E+03	-1.3E+04	-8.8E+03	-4.1E+03
Gas, natural, in ground	-6.8E+04	-1.9E+05	-8.7E+04	-1.8E+05	2.5E+05	-4.7E+04	-3.9E+04	-3.3E+04	1.7E+04	-5.2E+04	-6.9E+04	-6.6E+04
Gypsum, in ground	3.1E-03	3.0E-03	4.7E-03	2.1E-02	5.3E-03	4.2E-03	4.0E-03	4.8E-03	4.0E-03	3.1E-03	4.7E-03	4.2E-03
Iron, 46% in ore, 25% in crude ore, in ground	-2.3E-01	-2.9E-01	-3.5E-01	-3.3E-01	-4.7E-01	-3.3E-01	-3.1E-01	-3.5E-01	-3.2E-01	-2.5E-01	-3.3E-01	-3.3E-01
Kaolinite, 24% in crude ore, in ground	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.5E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.0E-03	-2.4E-03	-2.0E-03
Kieserite, 25% in crude ore, in ground	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.6E-01	-1.7E-01	-1.6E-01
Lanthanum, in crude ore, in ground	4.7E-18	4.7E-18	7.6E-18	6.6E-18	8.6E-18	6.8E-18	6.4E-18	7.9E-18	6.5E-18	4.3E-18	6.8E-18	6.7E-18
Lead (Pb, ore)	-4.1E+01	-4.2E+01	-4.5E+01	-4.9E+01	-5.8E+01	-4.7E+01	-4.6E+01	-5.0E+01	-6.3E+01	-4.1E+01	-6.2E+01	-4.7E+01
Magnesite, 60% in crude ore, in ground	-3.6E-07	2.8E-07	-4.0E-07	1.5E-08	1.3E-06	-3.5E-07	-1.7E-07	1.9E-07	-3.2E-07	-3.7E-07	1.4E-07	-3.3E-07
Magnesium, 0.13% in water	-5.9E-09	-5.9E-09	-6.0E-09	-5.9E-09	-6.5E-09	-6.1E-09	-6.2E-09	-6.3E-09	-6.0E-09	-6.2E-09	-7.1E-09	-5.9E-09
Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	1.2E-02	2.7E-02	2.0E-02	2.8E-02	2.8E-02	2.0E-02	2.2E-02	3.1E-02	1.6E-02	2.8E-02	2.6E-02	2.2E-02
Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	-3.3E+00	-3.3E+00	-4.9E+00	-4.4E+00	-5.2E+00	-4.6E+00	-4.3E+00	-5.2E+00	-4.4E+00	-4.0E+00	-4.6E+00	-4.7E+00
Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	-4.7E-01	-4.6E-01	-7.0E-01	-6.3E-01	-7.9E-01	-6.5E-01	-6.2E-01	-7.4E-01	-6.2E-01	-5.6E-01	-6.6E-01	-6.7E-01
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	9.8E+00	2.2E+01	1.6E+01	2.2E+01	2.3E+01	1.6E+01	1.8E+01	2.5E+01	1.3E+01	2.3E+01	2.1E+01	1.8E+01
Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	-1.7E+00	-1.7E+00	-2.6E+00	-2.3E+00	-2.9E+00	-2.4E+00	-2.3E+00	-2.7E+00	-2.3E+00	-2.1E+00	-2.4E+00	-2.5E+00
Molybdenum, 0.11% in sulfide, Mo 0.41% and Cu 0.36% in crude ore, in ground	2.0E+01	4.4E+01	3.3E+01	4.5E+01	4.5E+01	3.3E+01	3.6E+01	5.0E+01	2.6E+01	4.6E+01	4.3E+01	3.5E+01

Neodymium, in ground	1.1E-26	1.1E-26	1.8E-26	1.6E-26	2.1E-26	1.7E-26	1.6E-26	1.9E-26	1.6E-26	1.2E-26	1.7E-26	1.7E-26
Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	-1.9E-03	4.8E-03	-2.1E-03	-2.1E-03	-2.2E-03	-2.0E-03	-2.0E-03	-2.0E-03	-1.9E-03	-1.5E-02	-2.1E-03	-6.2E-03
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	1.6E-01	6.1E-01	3.5E-01	5.3E-01	6.7E-01	3.6E-01	4.2E-01	5.9E-01	3.1E-01	2.3E-01	4.3E-01	2.4E-01
Oil, crude, in ground	-1.1E+05	-1.3E+05	-1.4E+05	-2.2E+05	-1.6E+05	-1.2E+05	-1.1E+05	-1.2E+05	-1.2E+05	-9.6E+04	-1.6E+05	-1.2E+05
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-1.2E-03	-1.6E-03	-1.7E-03	-2.1E-03	-1.9E-03	-1.4E-03	-1.3E-03	-1.5E-03	-1.4E-03	-1.6E-03	-1.4E-03	-1.7E-03
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-2.8E-03	-3.9E-03	-4.1E-03	-5.1E-03	-4.7E-03	-3.4E-03	-3.0E-03	-3.6E-03	-3.3E-03	-3.9E-03	-3.4E-03	-4.0E-03
Phosphorus, 18% in apatite, 12% in crude ore, in ground	-5.1E-01	-5.0E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-5.1E-01	-4.7E-01	-5.1E-01	-1.8E+00	-5.1E-01	-9.4E-01
Phosphorus, 18% in apatite, 4% in crude ore, in ground	1.5E-02	4.9E-02	1.2E-02	1.7E-02	1.6E-02	1.3E-02	1.4E-02	1.4E-02	1.4E-02	-2.9E+00	1.8E-02	-9.6E-01
Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-4.0E-04	-4.7E-04	-4.7E-04	-5.0E-04	-5.5E-04	-4.5E-04	-4.3E-04	-4.6E-04	-4.3E-04	-4.4E-04	-4.9E-04	-4.5E-04
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-1.5E-03	-1.7E-03	-1.7E-03	-1.8E-03	-2.0E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.6E-03	-1.8E-03	-1.6E-03
Pyrite, in ground	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.4E-05	9.3E-05	9.4E-05	9.3E-05	9.4E-05
Raw Materials (unspecified)	2.8E-17	3.6E-17	2.0E-17	5.0E-17	2.2E-17	1.9E-17	2.0E-17	1.5E-17	2.1E-17	2.0E-17	3.7E-17	2.8E-17
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	-2.9E-03	-4.3E-03	-4.3E-03	-5.1E-03	-4.9E-03	-3.5E-03	-3.2E-03	-3.7E-03	-3.4E-03	-2.7E-03	-3.6E-03	-3.6E-03
Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	-9.2E-03	-1.4E-02	-1.4E-02	-1.6E-02	-1.5E-02	-1.1E-02	-1.0E-02	-1.2E-02	-1.1E-02	-8.5E-03	-1.1E-02	-1.2E-02
Rhenium, in crude ore, in ground	-8.9E-05	-1.2E-04	-1.3E-04	-1.5E-04	-1.5E-04	-1.1E-04	-1.0E-04	-1.2E-04	-1.1E-04	-9.1E-05	-1.2E-04	-1.1E-04
Silver, 0.01% in crude ore, in ground	-1.8E-01	-2.4E-02	-1.0E-01	-2.2E-01	-1.9E-01	-2.4E-01	-2.3E-01	-2.6E-01	-2.4E-01	-1.0E+00	-2.2E-01	-4.9E-01
Sodium chloride, in ground	-3.4E-03	-1.0E-03	-3.4E-03	-5.6E-03	-6.8E-03	-5.9E-03	-5.5E-03	-7.2E-03	-5.6E-03	-2.2E-02	-5.1E-03	-1.2E-02
sodium sulphate, various forms, in ground	-1.1E-02	5.9E-02	-1.3E-02	-4.2E-03	-2.9E-03	-1.1E-02	-9.9E-03	-1.0E-02	-9.1E-03	-5.9E+00	-2.8E-03	-2.0E+00
Stibnite, in ground	-5.5E-05	-5.2E-05	-6.3E-05	-4.5E-05	-6.1E-05	-6.1E-05	-6.4E-05	-5.9E-05	-6.1E-05	-4.7E-05	-7.5E-05	-5.6E-05
Sulfur, in ground	-2.2E-01	-2.2E-01	-2.2E-01	-3.1E-01	-2.5E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.2E-01	-2.3E-01	-2.9E-01	-2.2E-01
sylvite, 25 % in sylvinite, in ground	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.2E-04	-6.0E-04	-6.2E-04
Talc, in ground	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.3E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.0E-04	-1.2E-04	-1.0E-04
Tin, 79% in cassiterite, 0.1% in crude ore, in ground	-9.4E-02	-5.1E-02	-6.5E-02	-1.1E-01	-1.0E-01	-1.2E-01	-1.1E-01	-1.2E-01	-1.2E-01	-3.3E-01	-1.2E-01	-1.7E-01
Ulexite, in ground	-2.9E-03	-3.0E-03	-3.0E-03	-3.0E-03	-3.6E-03	-3.1E-03	-3.1E-03	-3.2E-03	-3.1E-03	-3.4E-03	-3.5E-03	-3.1E-03
Uranium, in ground	-7.6E-01	-7.0E-01	-7.4E-01	-5.6E-01	-7.0E-01	-7.1E-01	-7.8E-01	-6.2E-01	-5.7E-01	-5.5E-01	-9.2E-01	-6.4E-01
Zinc (Zn, ore)	1.6E+02	1.6E+02	2.7E+02	2.3E+02	3.0E+02	2.4E+02	2.2E+02	2.8E+02	2.3E+02	1.6E+02	2.4E+02	2.4E+02
Zirconia, as baddeleyite, in ground	-6.2E-07	-2.2E-08	-3.0E-07	-7.5E-07	-6.1E-07	-8.0E-07	-7.7E-07	-8.9E-07	-8.1E-07	-3.7E-06	-7.5E-07	-1.7E-06

Table 47: Lithuania acidification impacts by pollutant (kg SO_2 equivalent)

Substances	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total	-2.3E+05	-2.4E+05	-3.1E+05	-3.7E+05	-3.2E+05	-2.9E+05	-2.7E+05	-3.0E+05	-2.4E+05	-2.4E+05	-3.3E+05	-2.7E+05
Ammonia	5.0E+02	5.5E+03	4.2E+03	4.1E+03	1.5E+03	1.1E+03	1.3E+03	3.6E+02	5.7E+03	3.1E+03	6.4E+03	5.5E+03
Nitrogen oxides (NO and NO_2 as NO_2)	-3.2E+04	7.9E+03	-2.7E+04	-6.0E+04	-4.9E+04	-7.3E+02	2.2E+04	2.2E+04	-1.0E+04	1.8E+04	-4.3E+04	-3.0E+04
Sulfur dioxide	-1.9E+05	-2.5E+05	-2.5E+05	-3.0E+05	-2.6E+05	-2.0E+05	-1.9E+05	-2.1E+05	-1.8E+05	-1.9E+05	-2.1E+05	-2.2E+05
Sulphur oxides (SO_2 and SO_3 as SO_2)	-1.2E+04	-6.4E+03	-3.3E+04	-1.1E+04	-1.3E+04	-8.8E+04	-1.1E+05	-1.1E+05	-5.2E+04	-7.7E+04	-8.2E+04	-2.1E+04

Table 48: Lithuania eutrophication impacts by pollutant (kg PO_4 equivalent)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		1.6E+04	-9.1E+02	1.1E+04	9.3E+03	1.7E+02	8.2E+02	4.0E+03	-1.3E+03	4.2E+03	1.1E+04	-6.2E+03	5.2E+03
Ammonia	air	1.1E+02	1.2E+03	9.3E+02	9.1E+02	3.3E+02	2.4E+02	2.8E+02	8.0E+01	1.3E+03	6.8E+02	1.4E+03	1.2E+03
Nitrate	air	5.2E-01	5.3E-01	5.0E-01	5.9E-01	6.6E-01	5.5E-01	5.4E-01	5.6E-01	7.9E-01	5.2E-01	7.7E-01	5.5E-01
Nitrogen oxides (NO and NO_2 as NO_2)	air	-8.4E+03	2.1E+03	-7.0E+03	-1.6E+04	-1.3E+04	-1.9E+02	5.8E+03	5.6E+03	-2.6E+03	4.7E+03	-1.1E+04	-7.9E+03
Nitrous oxide	air	-1.8E+02	1.7E+03	-1.1E+02	-1.5E+02	-1.3E+02	2.4E+02	8.3E+01	7.3E+01	6.4E+01	-8.1E+02	4.8E+01	-2.5E+02
Phosphorus	air	-5.8E+01	-5.8E+01	-5.6E+01	-5.7E+01	-6.7E+01	-5.7E+01	-5.7E+01	-5.6E+01	-5.7E+01	-5.9E+01	-6.6E+01	-5.7E+01
Ammonia (NH_4^+, NH_3, as N)	water	3.0E+04	8.1E+02	2.6E+04	3.1E+04	2.2E+04	6.8E+03	5.1E+03	1.6E+03	1.7E+03	1.5E+04	3.6E+03	2.1E+04
Ammonium, ion	water	-5.9E+01	-3.8E+01	-6.9E+01	-6.6E+01	-6.3E+01	-7.2E+01	-7.4E+01	-7.6E+01	-6.6E+01	-1.1E+02	-6.7E+01	-8.0E+01
COD, Chemical Oxygen Demand	water	-2.9E+03	-3.6E+03	-3.9E+03	-2.8E+03	-4.1E+03	-3.3E+03	-3.2E+03	-3.6E+03	-3.3E+03	-3.0E+03	-2.5E+03	-3.6E+03
Nitrate	water	8.9E+02	9.0E+02	8.7E+02	8.8E+02	9.5E+02	8.8E+02	8.8E+02	8.7E+02	8.8E+02	8.7E+02	9.4E+02	8.7E+02
Nitrite	water	-2.8E-01	-2.6E-01	-3.0E-01	-2.8E-01	-2.1E-01	-3.1E-01	-3.1E-01	-3.1E-01	-2.8E-01	-4.8E-01	-2.3E-01	-3.7E-01
Nitrogen	water	1.4E+03	1.2E+03	1.3E+03	1.2E+03	1.2E+03	1.4E+03	1.5E+03	1.5E+03	1.3E+04	1.4E+03	8.2E+03	1.4E+03
Nitrogen - as total N	water	8.1E-01	4.5E-01	8.2E-01	7.9E-01	7.7E-01	8.0E-01	8.1E-01	8.0E-01	7.4E-01	8.2E-01	7.5E-01	8.1E-01
Phosphate	water	-3.9E+03	-4.2E+03	-5.9E+03	-5.3E+03	-6.4E+03	-5.6E+03	-5.4E+03	-6.4E+03	-5.4E+03	-6.3E+03	-5.7E+03	-6.2E+03
Phosphorus	water	-8.2E+02	-8.2E+02	-8.2E+02	-8.1E+02	-8.3E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.2E+02	-8.6E+02	-8.2E+02	-8.4E+02
Phosphorus - as total P	water	-9.7E-07	-9.5E-07	-9.7E-07	-9.7E-07	-9.7E-07	1.3E+03	-9.7E-07	-9.7E-07	-9.6E-07	-9.7E-07	-9.7E-07	-9.7E-07
Nitrogen	soil	2.0E-05	1.3E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05	2.0E-05
Phosphorus	soil	-5.4E+01	-6.5E+01	-6.2E+01	-6.7E+01	-5.9E+01	-5.6E+01	-5.4E+01	-5.7E+01	-5.3E+01	-5.3E+01	-6.2E+01	-5.8E+01

Table 49: Lithuania human toxicity impacts by pollutant (kg 1,4-DCB equivalents)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global ren	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		-1.2E+08	-1.2E+08	-1.9E+08	-1.7E+08	-2.1E+08	-1.7E+08	-1.6E+08	-2.0E+08	-1.5E+08	-1.2E+08	-1.6E+08	-1.7E+08
Acenaphthene	air	-5.9E+01	-1.1E+02	-7.8E+01	-1.1E+02	-7.4E+01	-4.1E+01	-3.3E+01	-3.1E+01	-2.8E+01	-3.7E+01	-3.5E+01	-5.6E+01
Acrolein	air	-1.3E+00	-1.2E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00	-1.3E+00
Ammonia	air	3.1E+01	3.5E+02	2.7E+02	2.6E+02	9.3E+01	6.8E+01	7.9E+01	2.3E+01	3.6E+02	1.9E+02	4.0E+02	3.4E+02
Antimony	air	-2.7E+03	2.3E+04	-2.3E+03	-1.7E+03	-2.5E+03	-1.1E+03	-1.6E+03	-2.8E+03	-9.1E+02	-1.1E+03	-9.5E+02	-1.4E+03
Arsenic	air	-9.3E+05	-6.7E+05	-1.2E+06	-1.3E+06	-1.3E+06	-8.3E+05	-7.9E+05	-8.3E+05	-8.6E+05	-9.0E+05	-8.1E+05	-1.1E+06
Barium	air	-2.7E+03	-2.8E+03	-3.8E+03	-3.3E+03	-4.0E+03	-3.7E+03	-3.7E+03	-4.2E+03	-3.5E+03	-3.3E+03	-3.7E+03	-3.5E+03
Benzene	air	-1.6E+05	-2.3E+05	-2.0E+05	-2.0E+05	-2.2E+05	-1.7E+05	-1.7E+05	-2.0E+05	-1.5E+05	-1.4E+05	-1.7E+05	-1.7E+05
Benzene, ethyl-	air	-5.5E+00	-7.5E+00	-7.8E+00	1.2E+02	-8.8E+00	-6.5E+00	-5.9E+00	-6.7E+00	-6.3E+00	-5.0E+00	-6.7E+00	-6.6E+00
Benzene, pentachloro-	air	5.4E-01	5.5E-01	5.6E-01	5.4E-01	6.4E-01	5.5E-01	5.5E-01	5.6E-01	5.5E-01	5.2E-01	6.1E-01	5.5E-01
Beryllium	air	-4.4E+03	-5.1E+03	-5.3E+03	-5.4E+03	-4.9E+03	-5.3E+03	-5.4E+03	-5.6E+03	-4.8E+03	-5.4E+03	-4.5E+03	-4.8E+03
Butadiene [1,3-Butadiene]	air	1.3E+05	1.2E+05	1.3E+05	1.2E+05	1.1E+05	1.3E+05	1.3E+05	1.3E+05	1.0E+05	1.3E+05	1.1E+05	1.2E+05
Cadmium	air	-2.1E+05	-1.5E+05	-2.8E+05	-3.1E+05	-3.0E+05	-2.1E+05	-1.9E+05	-2.2E+05	-2.0E+05	-2.1E+05	-2.1E+05	-2.6E+05
Carbon disulphide	air	1.4E+02	1.8E+02	2.8E+02	2.5E+02	3.2E+02	2.3E+02	2.3E+02	3.1E+02	1.8E+02	1.5E+02	2.3E+02	2.3E+02
Carbon tetrachloride [Tetrachloromethane]	air	3.9E+01	9.1E+00	8.9E+01	3.4E+01	2.4E+01	1.5E+01	4.7E+00	2.0E+00	3.5E+00	-8.4E+01	1.2E+00	-1.3E+00
Chlorinated Matter (unspecified, as Cl)	air	-4.7E-06	-1.1E-07	-2.3E-06	-5.7E-06	-4.6E-06	-6.1E-06	-5.9E-06	-6.7E-06	-6.2E-06	-2.8E-05	-5.7E-06	-1.3E-05
Chloroform [Trichloromethane]	air	2.1E+00	-7.7E-03	1.2E+00	1.7E+00	1.3E+00	9.1E-01	3.5E-01	2.4E-01	3.1E-01	6.6E-01	1.9E-01	1.7E+00
Chromium VI	air	-2.2E+05	1.5E+04	1.1E+06	1.8E+06	2.1E+06	6.6E+05	7.0E+05	1.1E+06	1.7E+06	1.8E+06	1.7E+06	1.6E+06
Cobalt	air	-6.0E+04	-1.0E+05	-7.7E+04	-1.3E+05	-6.9E+04	-3.0E+04	-2.0E+04	-1.5E+04	-1.4E+04	-3.0E+04	-1.6E+04	-5.3E+04
Copper	air	-1.7E+05	-1.5E+05	-2.5E+05	-2.3E+05	-2.9E+05	-2.3E+05	-2.1E+05	-2.6E+05	-2.2E+05	-1.7E+05	-2.2E+05	-2.3E+05
Dichloromethane	air	2.7E-01	-1.7E-01	8.2E-02	1.9E-01	9.1E-02	2.1E-02	-9.2E-02	-1.2E-01	-1.0E-01	-2.7E-02	-1.3E-01	1.8E-01
Dioxins and furans- as ITEQ	air	3.2E+01	2.5E+04	2.6E+03	7.2E+01	7.4E+01	8.9E+03	1.1E+04	1.1E+04	4.2E+03	7.5E+03	8.0E+03	1.1E+03
Dioxins and furans- as WHO TEQ	air	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.4E+02	-2.5E+02	-2.4E+02	-2.4E+02	-2.4E+02
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.4E+05	-2.5E+05	-2.5E+05	-2.5E+05	-3.2E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-2.5E+05	-3.0E+05	-2.5E+05
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.8E+02	2.9E+00	4.9E+01	1.4E+02	6.5E+01	9.2E+01	5.1E+01	8.2E+01	8.6E+01	5.4E+01	1.7E+01	1.2E+02
Ethane, 1,2-dichloro-	air	-4.3E+01	-4.6E+01	-4.9E+01	-4.6E+01	-5.9E+01	-4.8E+01	-4.8E+01	-4.9E+01	-4.7E+01	-5.0E+01	-5.6E+01	-4.9E+01
Ethylene [Ethene]	air	1.4E+01	1.5E+00	-8.3E+00	-8.2E+00	2.1E+00	-8.8E+00	-8.0E+00	-1.4E+01	-5.3E+00	1.1E+00	1.4E+01	-4.4E+00
Ethylene oxide [1,2-Epoxyethane]	air	-1.6E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04	-1.7E+04

Formaldehyde [Methanal]	air	-1.1E+02	-1.6E+02	-1.4E+02	-1.6E+02	-1.4E+02	-1.1E+02	-1.0E+02	-1.1E+02	-9.9E+01	-9.7E+01	-1.0E+02	-1.2E+02
Hexachlorobenzene	air	7.3E+02	2.1E+03	7.5E+02	1.5E+03	4.3E+03	7.8E+02	1.1E+03	1.8E+03	8.7E+02	5.9E+02	1.9E+03	6.2E+02
Hydrocarbons (unspecified)	air	-5.6E-01	9.2E+00	-5.4E-01	-6.9E-01	-8.3E-01	-6.2E-01	-6.0E-01	-6.4E-01	-1.1E+00	-5.6E-01	-1.0E+00	-6.2E-01
Hydrogen chloride	air	-8.2E+02	4.2E+02	-7.3E+02	-1.0E+03	7.1E+02	-3.7E+02	-2.8E+02	-3.5E+02	-5.3E+02	-4.0E+02	-8.8E+02	-7.3E+02
Hydrogen fluoride	air	-4.1E+06	-4.5E+06	-6.7E+06	-5.8E+06	-7.5E+06	-6.2E+06	-5.9E+06	-7.3E+06	-6.1E+06	-4.5E+06	-6.4E+06	-6.0E+06
Hydrogen sulfide	air	-1.2E+02	-1.4E+02	-1.2E+02	-1.2E+02	-2.5E+01	-1.2E+02	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02
Lead	air	-5.0E+02	-1.1E+03	1.7E+03	1.2E+01	5.6E+02	1.4E+03	1.4E+03	2.7E+03	9.7E+02	-8.3E+02	1.5E+03	5.1E+02
Mercury	air	-5.1E+03	9.0E+03	-3.5E+03	-3.5E+03	-2.5E+03	-2.6E+03	-2.9E+03	-3.3E+03	-2.9E+03	-9.7E+02	-2.9E+03	-4.0E+03
Methyl bromide [Bromomethane]	air	2.2E-06	2.2E-06	3.5E-06	3.0E-06	3.9E-06	3.1E-06	2.9E-06	3.6E-06	3.0E-06	2.1E-06	3.1E-06	3.1E-06
Molybdenum	air	-4.3E+03	-8.9E+03	-5.8E+03	-9.3E+03	-5.1E+03	-2.7E+03	-1.9E+03	-1.8E+03	-1.5E+03	-2.6E+03	-1.4E+03	-4.2E+03
m-Xylene	air	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.5E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.1E-01	-2.5E-01	-2.1E-01
Nickel	air	-1.1E+06	-1.2E+06	-1.4E+06	-1.7E+06	-1.4E+06	-1.0E+06	-8.6E+05	-1.0E+06	-8.1E+05	-8.5E+05	-7.9E+05	-1.2E+06
Nitrogen oxides (NO and NO_2 as NO_2)	air	-7.8E+04	1.9E+04	-6.5E+04	-1.4E+05	-1.2E+05	-1.8E+03	5.3E+04	5.2E+04	-2.4E+04	4.4E+04	-1.0E+05	-7.2E+04
o-Xylene	air			1.1E+01		1.1E+01	4.5E+01	2.0E+01	2.0E+01	1.6E+01	1.6E+01	1.6E+01	1.6E+01
PAH, polycyclic aromatic hydrocarbons	air	-1.1E+08	-1.1E+08	-1.7E+08	-1.5E+08	-1.9E+08	-1.5E+08	-1.4E+08	-1.8E+08	-1.5E+08	-1.0E+08	-1.5E+08	-1.5E+08
Particulates, < 2.5 um	air	-1.5E+04	-1.6E+04	-2.1E+04	-2.0E+04	-2.4E+04	-1.9E+04	-1.9E+04	-2.1E+04	-1.9E+04	-1.6E+04	-2.0E+04	-2.0E+04
Particulates, > 2.5 um, and < 10um	air	-2.1E+04	-2.3E+04	-3.2E+04	-3.0E+04	-3.8E+04	-2.9E+04	-2.8E+04	-3.3E+04	-2.8E+04	-2.2E+04	-3.0E+04	-3.0E+04
Pentachlorophenol	air	-4.1E-01	1.3E-01	-4.4E-01	-4.3E-01	-5.2E-01	-4.5E-01	-4.5E-01	-4.7E-01	-4.4E-01	-4.8E-01	-5.1E-01	-4.5E-01
Phenol	air	8.4E-01	1.2E+00	1.1E+00	8.3E-01	1.2E+00	8.5E-01	8.6E-01	8.2E-01	8.6E-01	7.7E-01	1.2E+00	8.1E-01
Propylene oxide	air	4.3E+02	4.3E+02	4.0E+02	4.0E+02	5.0E+02	7.4E+02	7.8E+02	3.9E+02	4.9E+02	3.9E+02	3.9E+02	3.9E+02
Selenium	air	-1.1E+05	-1.4E+05	-1.5E+05	-1.6E+05	-1.6E+05	-1.2E+05	-1.2E+05	-1.3E+05	-1.1E+05	-1.1E+05	-1.2E+05	-1.3E+05
Sodium dichromate	air	-6.4E+03	-1.5E+04	-2.4E+05	-1.6E+05	-2.2E+05	-1.8E+05	-1.4E+05	-2.6E+05	-1.5E+05	-1.2E+04	-9.7E+04	-1.8E+05
Styrene	air	-1.1E-03	-9.3E-04	1.7E+00	1.6E+00	1.6E+00	5.3E+00	1.8E+00	1.9E+00	2.4E+00	2.5E+00	2.6E+00	2.3E+00
Sulfur dioxide	air	-1.5E+04	-2.0E+04	-2.0E+04	-2.4E+04	-2.0E+04	-1.6E+04	-1.5E+04	-1.7E+04	-1.5E+04	-1.5E+04	-1.7E+04	-1.8E+04
Sulphur oxides (SO_2 and SO_3 as SO_2)	air	-9.8E+02	-5.1E+02	-2.6E+03	-8.9E+02	-1.0E+03	-7.1E+03	-8.6E+03	-8.8E+03	-4.2E+03	-6.1E+03	-6.6E+03	-1.7E+03
Tetrachloroethylene	air	1.0E+00	-8.8E-02	5.5E-01	8.1E-01	5.7E-01	3.9E-01	1.1E-01	3.7E-02	7.5E-02	2.7E-01	2.2E-02	8.1E-01
Thallium	air	-5.9E+03	-5.8E+03	1.3E+05	1.3E+05	1.3E+05	6.2E+04	6.1E+04	6.1E+04	1.8E+05	1.8E+05	1.8E+05	1.9E+05
Tin	air	-6.3E-01	1.0E+01	-9.3E-01	-8.1E-01	-1.0E+00	-8.6E-01	-8.1E-01	-9.1E-01	-8.4E-01	-7.7E-01	-8.7E-01	-9.1E-01
Toluene	air	-8.7E+00	-2.3E+01	6.3E+01	3.7E+01	3.6E+01	2.0E+02	1.5E+02	1.5E+02	1.1E+02	1.4E+02	1.5E+02	7.4E+01
Trichloroethylene	air	8.7E+01	1.0E+00	5.0E+01	7.1E+01	5.2E+01	3.8E+01	1.6E+01	1.1E+01	1.4E+01	2.9E+01	9.5E+00	7.0E+01

Vanadium	air	-3.6E+05	-6.6E+05	-4.6E+05	-7.0E+05	-4.2E+05	-2.5E+05	-2.0E+05	-1.9E+05	-1.7E+05	-2.9E+05	-1.7E+05	-3.7E+05
Vinyl chloride	air	-5.6E+01	-6.9E+01	-9.9E+01	-8.4E+01	-1.1E+02	-9.1E+01	-8.9E+01	-1.1E+02	-9.0E+01	-6.8E+01	-9.7E+01	-8.7E+01
Zinc	air	2.6E+04	2.6E+04	4.3E+04	3.7E+04	4.9E+04	3.9E+04	3.6E+04	4.5E+04	3.7E+04	2.6E+04	3.9E+04	3.8E+04
Acenaphthene	water	-2.5E+02	-3.9E+02	-4.1E+02	-4.9E+02	-4.5E+02	-3.1E+02	-2.7E+02	-3.2E+02	-2.9E+02	-2.0E+02	-3.0E+02	-3.2E+02
Acenaphthylene	water	-5.0E+00	-2.1E+01	-1.3E+01	-2.4E+01	-2.8E+01	-1.1E+01	-7.8E+00	-1.3E+01	-2.7E+01	-2.1E+00	-2.4E+01	-1.2E+01
Antimony	water	-1.1E+05	-1.1E+03	-1.2E+05	-3.0E+05	-1.5E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.2E+05	-1.3E+05	-1.8E+05	-1.2E+05
Arsenic	water	4.6E+04	1.7E+03	3.5E+04	4.4E+04	3.7E+04	1.4E+04	1.7E+04	3.7E+03	1.2E+04	1.8E+04	1.8E+04	2.1E+04
Arsenic, ion	water	-1.2E+05	-1.2E+05	-1.9E+05	-1.7E+05	-2.1E+05	-1.7E+05	-1.6E+05	-2.0E+05	-1.6E+05	-1.3E+05	-1.7E+05	-1.7E+05
Barite	water	-6.3E+05	-1.7E+06	-9.4E+05	-1.5E+06	2.0E+05	-3.7E+05	-2.3E+05	-2.1E+05	-3.6E+04	-2.8E+05	-2.5E+05	-6.0E+05
Barium	water	-2.2E+05	1.0E+04	-3.2E+05	-3.3E+05	-3.6E+05	-2.8E+05	-2.6E+05	-3.0E+05	-2.6E+05	-2.2E+05	-1.1E+05	-2.8E+05
Benzene	water	-5.0E+04	-5.9E+04	-6.1E+04	-6.7E+04	-7.2E+04	-5.4E+04	-5.1E+04	-5.5E+04	-5.3E+04	-4.7E+04	-6.0E+04	-5.6E+04
Benzene, chloro-	water	-2.6E-01	-1.8E-02	-1.3E-01	-3.1E-01	-2.6E-01	-3.4E-01	-3.3E-01	-3.7E-01	-3.4E-01	-1.5E+00	-3.2E-01	-7.2E-01
Beryllium	water	-3.9E+04	-3.9E+04	-5.5E+04	-4.8E+04	-6.2E+04	-5.2E+04	-5.0E+04	-5.9E+04	-5.0E+04	-4.3E+04	-2.9E+04	-5.2E+04
Cadmium	water	8.5E+01	2.3E+02	2.5E+01	4.8E+01	3.8E+01	1.4E+01	7.3E+00	-5.0E-01	6.8E+00	1.2E+01	6.1E+01	3.4E+01
Cadmium, ion	water	-1.0E+02	-1.1E+02	-1.0E+02	-1.3E+02	-1.3E+02	-1.1E+02	-1.1E+02	-1.2E+02	-1.6E+02	-1.4E+02	-1.5E+02	-1.3E+02
Chlorinated solvents, unspecified	water	-8.2E-01	-6.6E-01	-9.2E-01	-1.4E+00	-1.4E+00	-1.1E+00	-1.1E+00	-1.3E+00	-1.1E+00	-1.8E+00	-1.3E+00	-1.5E+00
Chloroform [Trichloromethane]	water	-7.0E-04	5.1E-05	-2.9E-04	-8.6E-04	-6.8E-04	-9.3E-04	-8.9E-04	-1.0E-03	-9.5E-04	-4.6E-03	-8.6E-04	-2.1E-03
Chromium	water	1.4E+02	8.0E+01	5.7E+01	1.1E+02	7.4E+01	5.6E+01	4.1E+01	4.3E+01	5.5E+01	3.8E+01	1.1E+02	6.5E+01
Chromium VI	water	-3.0E+03	-3.0E+03	-4.9E+03	-4.3E+03	-5.4E+03	-4.4E+03	-4.1E+03	-5.1E+03	-4.2E+03	-3.2E+03	-4.4E+03	-4.4E+03
Cobalt	water	-1.9E+03	-1.4E+03	-2.9E+03	-2.3E+03	-3.0E+03	-2.7E+03	-2.4E+03	-2.9E+03	-2.5E+03	-2.1E+03	1.5E+03	-2.8E+03
Copper	water	8.7E+01	3.7E+02	1.6E+01	5.7E+01	2.2E+01	5.4E+01	2.7E+01	3.9E+01	4.8E+01	4.5E+01	1.0E+02	5.5E+01
Copper, ion	water	1.0E+03	1.0E+03	1.0E+03	9.9E+02	1.2E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.1E+03	1.0E+03
Di(2-ethylhexyl)phthalate (DEHP)	water	3.5E+01	8.0E-01	1.6E+01	1.9E+01	2.0E+01	7.7E+00	4.6E+00	3.8E+00	3.7E+00	9.3E+00	4.6E+00	2.2E+01
Dichloromethane	water	-2.7E+00	-5.0E+00	-4.5E+00	-5.5E+00	-1.8E+00	-3.4E+00	-2.9E+00	-3.5E+00	-2.7E+00	-2.2E+00	-3.3E+00	-3.5E+00
Dichromate	water	-2.9E+00	-3.0E+00	-4.5E+00	-4.0E+00	-5.1E+00	-4.1E+00	-3.9E+00	-4.7E+00	-3.9E+00	-2.9E+00	-4.1E+00	-4.1E+00
Ethane, 1,1,1-trichloro-, HCFC-140	water	-7.2E-07	-8.5E-07	-7.0E-07	-8.3E-07	-9.6E-07	-7.7E-07	-7.5E-07	-7.9E-07	-1.2E-06	-7.2E-07	-1.1E-06	-7.7E-07
Ethene	water	-4.9E+00	-5.1E+00	-5.1E+00	-5.1E+00	-6.2E+00	-5.1E+00	-5.0E+00	-5.1E+00	-5.0E+00	-5.0E+00	-6.0E+00	-5.1E+00
Ethene, chloro-	water	-1.4E+00	-1.4E+00	-2.2E+00	-1.9E+00	-2.4E+00	-1.9E+00	-1.8E+00	-2.3E+00	-1.9E+00	-1.4E+00	-2.0E+00	-2.0E+00
Ethene, tetrachloro-	water	4.2E-07	3.6E-07	4.4E-07	4.1E-07	3.9E-07	4.1E-07	4.2E-07	4.1E-07	3.6E-07	4.2E-07	3.9E-07	4.2E-07
Ethene, trichloro-	water	3.7E-01	8.2E-03	1.8E-01	3.4E-01	2.8E-01	1.1E-01	8.5E-02	7.6E-02	9.5E-02	1.5E-01	4.7E-02	2.0E-01

Ethylbenzene	water	-2.6E+00	-4.1E+00	-4.3E+00	-5.1E+00	-4.8E+00	-3.3E+00	-2.8E+00	-3.4E+00	-3.1E+00	-2.1E+00	-3.2E+00	-3.4E+00
Ethylene dichloride	water	-3.0E+02	-3.0E+02	-3.0E+02	-2.9E+02	-3.6E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.0E+02	-3.3E+02	-3.5E+02	-3.1E+02
Ethylene oxide	water	-5.2E+02	-5.1E+02	-5.1E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.2E+02	-5.4E+02	-5.2E+02	-5.3E+02
Formaldehyde	water	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-6.0E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-4.9E-01	-5.9E-01	-4.9E-01
Fungicides, unspecified	water	8.5E-03	8.5E-03	8.5E-03	8.5E-03	1.0E-02	8.5E-03	8.5E-03	8.5E-03	8.5E-03	8.4E-03	1.0E-02	8.4E-03
Herbicides, unspecified	water	-3.9E-06	-9.9E-08	-1.9E-06	-4.7E-06	-3.8E-06	-5.1E-06	-4.9E-06	-5.6E-06	-5.1E-06	-2.3E-05	-4.7E-06	-1.1E-05
Insecticides, unspecified	water	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Lead	water	1.7E+03	1.7E+03	1.2E+03	1.3E+03	1.3E+03	1.8E+03	1.0E+03	9.2E+02	9.5E+02	9.9E+02	3.6E+03	1.2E+03
Mercury	water	-2.0E+02	-5.9E+02	-3.5E+02	-1.1E+02	-4.2E+02	-5.8E+02	-5.2E+02	-5.9E+02	-6.3E+02	-6.6E+02	1.3E+02	-5.8E+02
Metals (unspecified)	water	-5.9E-01	-5.8E-01	-5.7E-01	-5.9E-01	-5.8E-01	-5.9E-01	-5.9E-01	-5.9E-01	-6.0E-01	-5.9E-01	-5.9E-01	-5.9E-01
Molybdenum	water	-8.5E+04	3.9E+05	-1.1E+05	-9.2E+04	-1.2E+05	-1.0E+05	-1.0E+05	-1.1E+05	-9.4E+04	-9.1E+04	-1.1E+05	-9.9E+04
m-Xylene	water	6.2E-03	6.1E-03	6.4E-03	6.3E-03	6.3E-03	6.3E-03	6.3E-03	6.4E-03	6.1E-03	6.2E-03	6.2E-03	6.3E-03
Nickel	water	2.5E+04	7.3E+03	1.1E+04	2.0E+04	1.1E+04	1.5E+04	1.2E+04	1.1E+04	1.4E+04	1.5E+04	6.9E+04	1.5E+04
Nickel, ion	water	-1.4E+03	3.5E+02	-5.4E+03	-6.8E+03	5.7E+03	-2.6E+02	2.5E+03	3.9E+03	1.9E+03	-4.0E+03	3.8E+03	-5.1E+03
o-Xylene	water	2.9E-04	2.9E-04	4.6E-04	4.0E-04	5.2E-04	4.2E-04	3.9E-04	4.8E-04	4.0E-04	2.9E-04	4.2E-04	4.1E-04
PAH, polycyclic aromatic hydrocarbons	water	-2.2E+05	-3.4E+05	-3.6E+05	-4.3E+05	-4.0E+05	-2.7E+05	-2.3E+05	-2.8E+05	-2.7E+05	-1.7E+05	-2.7E+05	-2.8E+05
Phenol	water	-7.2E-01	-1.1E+00	-1.1E+00	-1.5E+00	-1.3E+00	-9.0E-01	-8.1E-01	-9.6E-01	-8.8E-01	-6.4E-01	-1.1E+00	-9.2E-01
Phthalate, dibutyl-	water	1.4E-08	4.4E-09	1.6E-08	8.5E-09	8.4E-10	1.1E-08	1.2E-08	1.0E-08	-1.1E-08	1.4E-08	-6.7E-09	1.1E-08
Propylene oxide	water	1.7E+03	1.7E+03	1.6E+03	1.6E+03	2.0E+03	3.0E+03	3.1E+03	1.6E+03	2.0E+03	1.6E+03	1.6E+03	1.6E+03
Selenium	water	-1.0E+06	-1.0E+06	-1.6E+06	-1.4E+06	-1.8E+06	-1.5E+06	-1.4E+06	-1.7E+06	-1.4E+06	-1.1E+06	-1.3E+06	-1.4E+06
Thallium	water	-6.2E+04	-1.1E+05	-1.0E+05	-1.3E+05	-1.0E+05	-6.8E+04	-5.9E+04	-7.0E+04	-5.1E+04	-5.4E+04	-5.6E+04	-8.1E+04
Tin, ion	water	6.6E-01	6.6E-01	6.0E-01	5.7E-01	7.0E-01	6.1E-01	6.2E-01	5.9E-01	6.2E-01	6.1E-01	1.1E+00	6.0E-01
Toluene	water	-4.8E+00	-7.9E+00	-8.0E+00	-9.7E+00	-9.0E+00	-6.2E+00	-5.4E+00	-6.5E+00	-5.9E+00	-4.0E+00	-6.1E+00	-6.4E+00
Tributyltin compounds	water	-2.2E+03	-2.4E+03	-3.4E+03	-3.2E+03	-3.9E+03	-3.0E+03	-2.9E+03	-3.4E+03	-2.9E+03	-2.3E+03	-3.1E+03	-3.1E+03
Vanadium, ion	water	-4.4E+06	-4.4E+06	-7.1E+06	-6.2E+06	-8.0E+06	-6.3E+06	-6.0E+06	-7.4E+06	-6.0E+06	-4.5E+06	-6.4E+06	-6.4E+06
Xylene - all isomers [Dimethylbenzene]	water	-5.6E+00	-9.1E+00	-9.3E+00	-1.1E+01	-1.0E+01	-7.1E+00	-6.2E+00	-7.5E+00	-6.8E+00	-4.6E+00	-7.0E+00	-7.4E+00
Zinc	water	7.0E+02	-1.9E+02	6.5E+01	3.4E+02	3.3E+02	4.5E+02	1.8E+02	2.3E+02	3.3E+02	2.7E+02	1.6E+03	3.2E+02
2,4-D	soil	5.3E+01	5.3E+01	5.2E+01	5.2E+01	6.5E+01	5.2E+01	5.3E+01	5.2E+01	5.3E+01	5.2E+01	6.3E+01	5.2E+01
Antimony	soil	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.9E-01	8.1E-01	8.4E-01	8.3E-01
Arsenic	soil	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.4E+05	3.0E+06	3.4E+05	1.9E+06	3.4E+05

Atrazine	soil	-6.4E-04	-5.7E-04	-6.2E-04	-7.3E-04	-7.9E-04	-7.0E-04	-6.9E-04	-7.2E-04	-9.6E-04	-1.0E-03	-9.4E-04	-8.1E-04
Barium	soil	-1.1E+04	-2.1E+04	-1.9E+04	-2.3E+04	-7.7E+03	-1.4E+04	-1.2E+04	-1.5E+04	-1.1E+04	-9.3E+03	-1.4E+04	-1.5E+04
Bentazone	soil	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.4E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	1.9E+00	2.3E+00	1.9E+00
Cadmium	soil	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	8.3E+03	1.3E+05	8.3E+03	8.3E+04	8.3E+03
Chlorothalonil	soil	5.5E+01	5.5E+01	5.4E+01	5.5E+01	5.4E+01	5.4E+01	5.4E+01	5.4E+01	5.5E+01	5.5E+01	5.4E+01	5.5E+01
Chromium	soil	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.5E+05	1.4E+06	1.5E+05	9.3E+05	1.5E+05
Chromium VI	soil	-1.1E+05	-1.1E+05	-1.7E+05	-1.5E+05	-1.9E+05	-1.5E+05	-1.5E+05	-1.8E+05	-1.5E+05	-1.1E+05	-1.6E+05	-1.5E+05
Cobalt	soil	-1.7E+01	-1.7E+01	-1.7E+01	-1.8E+01	-2.0E+01	-1.7E+01	-1.7E+01	-1.7E+01	-1.7E+01	-1.8E+01	-1.9E+01	-1.7E+01
Copper	soil	-7.8E+03	-7.8E+03	-8.1E+03	-8.0E+03	-8.3E+03	-8.0E+03	-8.0E+03	-8.2E+03	5.4E+04	-7.8E+03	3.0E+04	-8.0E+03
Cypermethrin	soil	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	2.9E+03	3.5E+03	2.9E+03
Dinoseb	soil	-1.3E-01	-1.3E-01	-3.3E-01	-1.8E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.8E-01	-2.1E-01	-1.6E-01	-3.1E-01	-1.4E-01
Glyphosate	soil	5.9E-02	5.9E-02	5.8E-02	5.9E-02	7.2E-02	5.8E-02	5.8E-02	5.8E-02	5.9E-02	5.8E-02	7.0E-02	5.8E-02
Lead	soil	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.9E+05	5.0E+06	5.9E+05	3.3E+06	5.9E+05
Linuron	soil	3.2E+02	3.2E+02	3.2E+02	3.2E+02	4.0E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.2E+02	3.8E+02	3.2E+02
Mercury	soil	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.9E+03	1.8E+04	1.9E+03	1.2E+04	1.9E+03
Metazachlor	soil	1.3E+02	7.2E+01	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.3E+02	1.3E+02	1.2E+02	1.3E+02	1.2E+02	1.3E+02
Metolachlor	soil	1.6E+02	1.6E+02	1.6E+02	1.6E+02	2.0E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.6E+02	1.9E+02	1.6E+02
Molybdenum	soil	-2.1E+01	-2.2E+01	-2.1E+01	-2.2E+01	-2.5E+01	-2.1E+01	-2.1E+01	-2.2E+01	-2.1E+01	-2.5E+01	-2.4E+01	-2.3E+01
Nickel	soil	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	6.3E+04	5.5E+05	6.3E+04	3.6E+05	6.3E+04
Pirimicarb	soil	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.9E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.1E-01	3.7E-01	3.1E-01
Selenium	soil	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03
Thallium	soil	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.2E-03	8.1E-03	8.2E-03	8.1E-03	8.2E-03
Tin	soil	-4.5E-04	1.2E-03	-4.6E-04	-1.9E-03	-2.6E-03	-2.2E-03	-1.9E-03	-3.1E-03	-1.9E-03	-1.3E-02	-1.5E-03	-6.4E-03
Vanadium	soil	-3.3E+02	-3.5E+02	-3.4E+02	-3.5E+02	-4.0E+02	-3.4E+02	-3.3E+02	-3.3E+02	-3.3E+02	-3.4E+02	-3.8E+02	-3.4E+02
Zinc	soil	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.5E+04	1.7E+05	1.5E+04	1.1E+05	1.5E+04

Table 50: Lithuania freshwater ecotoxicity impacts by pollutant (kg 1,4-DCB equivalents)

Substances	Compartment	Landfill	Incineration	Haase	Arrowbio	Global renewables	Ecodeco	Entsorga	Herhof	Bedminster	Linde	SRS	VKW
Total		-9.5E+06	-9.9E+06	-1.6E+07	-1.4E+07	-1.8E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.0E+07	-9.9E+06	-1.1E+07	-1.4E+07

Acenaphthene	air	-1.8E-02	-3.3E-02	-2.3E-02	-3.4E-02	-2.2E-02	-1.2E-02	-9.9E-03	-9.3E-03	-8.4E-03	-1.1E-02	-1.1E-02	-1.7E-02
Acrolein	air	-1.2E+01	-1.1E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01	-1.2E+01
Antimony	air	-1.5E+00	1.3E+01	-1.3E+00	-9.6E-01	-1.4E+00	-6.1E-01	-8.9E-01	-1.6E+00	-5.1E-01	-6.4E-01	-5.3E-01	-7.9E-01
Arsenic	air	-1.3E+02	-9.6E+01	-1.6E+02	-1.9E+02	-1.8E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.3E+02	-1.2E+02	-1.6E+02
Barium	air	-1.5E+02	-1.6E+02	-2.1E+02	-1.9E+02	-2.3E+02	-2.1E+02	-2.1E+02	-2.4E+02	-2.0E+02	-1.9E+02	-2.1E+02	-2.0E+02
Benzene	air	-6.9E-03	-1.0E-02	-8.8E-03	-8.6E-03	-9.8E-03	-7.6E-03	-7.5E-03	-8.7E-03	-6.7E-03	-6.4E-03	-7.4E-03	-7.3E-03
Benzene, ethyl-	air	-7.5E-04	-1.0E-03	-1.1E-03	1.6E-02	-1.2E-03	-8.7E-04	-8.0E-04	-9.0E-04	-8.4E-04	-6.7E-04	-9.1E-04	-8.9E-04
Benzene, pentachloro-	air	4.9E-04	5.0E-04	5.1E-04	4.9E-04	5.8E-04	5.0E-04	5.0E-04	5.1E-04	5.0E-04	4.7E-04	5.5E-04	5.0E-04
Benzo(a)pyrene	air	-5.1E+02	-4.9E+02	-8.3E+02	-7.2E+02	-9.3E+02	-7.4E+02	-7.0E+02	-8.7E+02	-7.1E+02	-5.2E+02	-7.5E+02	-7.4E+02
Beryllium	air	-3.3E+02	-3.8E+02	-4.0E+02	-4.1E+02	-3.7E+02	-4.0E+02	-4.1E+02	-4.2E+02	-3.6E+02	-4.1E+02	-3.4E+02	-3.6E+02
Butadiene [1,3-Butadiene]	air	1.9E-05	1.8E-05	1.9E-05	1.8E-05	1.6E-05	1.9E-05	2.0E-05	1.9E-05	1.5E-05	2.0E-05	1.6E-05	1.8E-05
Cadmium	air	-4.1E+02	-3.1E+02	-5.5E+02	-6.2E+02	-6.1E+02	-4.1E+02	-3.8E+02	-4.4E+02	-3.9E+02	-4.2E+02	-4.2E+02	-5.1E+02
Carbon disulphide	air	1.9E+00	2.4E+00	3.8E+00	3.4E+00	4.4E+00	3.2E+00	3.1E+00	4.2E+00	2.5E+00	2.0E+00	3.1E+00	3.1E+00
Carbon tetrachloride [Tetrachloromethane]	air	4.4E-05	1.0E-05	1.0E-04	3.8E-05	2.7E-05	1.7E-05	5.3E-06	2.3E-06	4.0E-06	-9.6E-05	1.4E-06	-1.5E-06
Chlorinated Matter (unspecified, as Cl)	air	-2.7E-11	-6.1E-13	-1.3E-11	-3.2E-11	-2.6E-11	-3.5E-11	-3.4E-11	-3.9E-11	-3.5E-11	-1.6E-10	-3.2E-11	-7.6E-11
Chloroform [Trichloromethane]	air	1.6E-05	-5.8E-08	9.2E-06	1.3E-05	9.5E-06	6.9E-06	2.7E-06	1.8E-06	2.4E-06	5.0E-06	1.4E-06	1.3E-05
Chromium VI	air	-4.9E-01	3.3E-02	2.5E+00	4.0E+00	4.8E+00	1.5E+00	1.6E+00	2.4E+00	3.9E+00	4.0E+00	3.8E+00	3.5E+00
Cobalt	air	-2.2E+03	-3.8E+03	-2.8E+03	-4.7E+03	-2.5E+03	-1.1E+03	-7.3E+02	-5.4E+02	-5.1E+02	-1.1E+03	-5.7E+02	-1.9E+03
Copper	air	-8.7E+03	-7.5E+03	-1.3E+04	-1.2E+04	-1.5E+04	-1.2E+04	-1.1E+04	-1.3E+04	-1.1E+04	-8.8E+03	-1.2E+04	-1.2E+04
Dichloromethane	air	4.5E-06	-2.8E-06	1.4E-06	3.1E-06	1.5E-06	3.5E-07	-1.6E-06	-2.0E-06	-1.8E-06	-4.6E-07	-2.1E-06	3.1E-06
Dioxins and furans- as ITEQ	air	3.5E-02	2.7E+01	2.9E+00	7.9E-02	8.2E-02	9.7E+00	1.2E+01	1.2E+01	4.7E+00	8.3E+00	8.8E+00	1.2E+00
Dioxins and furans- as WHO TEQ	air	-2.6E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.6E-01	-2.6E-01	-2.7E-01	-2.6E-01	-2.7E-01	-2.6E-01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	-2.7E+02	-2.8E+02	-2.8E+02	-2.8E+02	-3.5E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.8E+02	-2.7E+02	-3.3E+02	-2.8E+02
Ethane, 1,1,1-trichloro-, HCFC-140	air	1.3E-03	2.1E-05	3.6E-04	1.0E-03	4.8E-04	6.8E-04	3.8E-04	6.1E-04	6.4E-04	4.0E-04	1.2E-04	9.2E-04
Ethane, 1,2-dichloro-	air	-7.5E-04	-8.0E-04	-8.6E-04	-8.1E-04	-1.0E-03	-8.3E-04	-8.3E-04	-8.6E-04	-8.3E-04	-8.7E-04	-9.8E-04	-8.5E-04
Ethylene [Ethene]	air	3.1E-10	3.3E-11	-1.9E-10	-1.9E-10	4.7E-11	-2.0E-10	-1.8E-10	-3.2E-10	-1.2E-10	2.6E-11	3.1E-10	-9.9E-11
Ethylene oxide [1,2-Epoxyethane]	air	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01	-1.2E-01
Formaldehyde [Methanal]	air	-1.1E+03	-1.6E+03	-1.4E+03	-1.6E+03	-1.4E+03	-1.1E+03	-1.0E+03	-1.1E+03	-9.8E+02	-9.7E+02	-1.0E+03	-1.2E+03
Hexachlorobenzene	air	3.1E-04	8.7E-04	3.2E-04	6.5E-04	1.8E-03	3.3E-04	4.7E-04	7.8E-04	3.7E-04	2.5E-04	8.1E-04	2.6E-04
Hydrocarbons (unspecified)	air	-3.0E-10	4.8E-09	-2.8E-10	-3.6E-10	-4.4E-10	-3.3E-10	-3.2E-10	-3.4E-10	-5.7E-10	-3.0E-10	-5.4E-10	-3.2E-10

Hydrogen fluoride	air	-6.7E+03	-7.4E+03	-1.1E+04	-9.4E+03	-1.2E+04	-1.0E+04	-9.7E+03	-1.2E+04	-9.8E+03	-7.3E+03	-1.0E+04	-9.8E+03
Lead	air	-2.6E+00	-5.6E+00	8.6E+00	5.9E-02	2.9E+00	7.3E+00	7.2E+00	1.4E+01	5.0E+00	-4.3E+00	7.9E+00	2.6E+00
Mercury	air	-2.7E+02	4.7E+02	-1.8E+02	-1.9E+02	-1.3E+02	-1.4E+02	-1.6E+02	-1.7E+02	-1.5E+02	-5.1E+01	-1.5E+02	-2.1E+02
Methyl bromide [Bromomethane]	air	2.0E-10	2.0E-10	3.2E-10	2.8E-10	3.6E-10	2.9E-10	2.7E-10	3.4E-10	2.8E-10	2.0E-10	2.9E-10	2.9E-10
Molybdenum	air	-7.7E+01	-1.6E+02	-1.0E+02	-1.7E+02	-9.1E+01	-4.8E+01	-3.5E+01	-3.2E+01	-2.6E+01	-4.7E+01	-2.6E+01	-7.5E+01
m-Xylene	air	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-4.1E-04	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-3.4E-04	-4.0E-04	-3.4E-04
Nickel	air	-2.0E+04	-2.1E+04	-2.5E+04	-3.1E+04	-2.6E+04	-1.8E+04	-1.6E+04	-1.8E+04	-1.5E+04	-1.5E+04	-1.4E+04	-2.1E+04
o-Xylene	air			8.2E-03		8.2E-03	3.4E-02	1.5E-02	1.5E-02	1.2E-02	1.2E-02	1.2E-02	1.2E-02
PAH, polycyclic aromatic hydrocarbons	air	-3.2E+04	-3.2E+04	-5.2E+04	-4.5E+04	-5.8E+04	-4.6E+04	-4.3E+04	-5.4E+04	-4.4E+04	-3.1E+04	-4.6E+04	-4.6E+04
Pentachlorophenol	air	-8.5E-01	2.7E-01	-9.1E-01	-8.9E-01	-1.1E+00	-9.3E-01	-9.4E-01	-9.6E-01	-9.1E-01	-1.0E+00	-1.1E+00	-9.3E-01
Phenol	air	2.5E+00	3.6E+00	3.1E+00	2.4E+00	3.5E+00	2.5E+00	2.5E+00	2.4E+00	2.5E+00	2.2E+00	3.4E+00	2.4E+00
Propylene oxide	air	1.3E-02	1.2E-02	1.2E-02	1.2E-02	1.5E-02	2.2E-02	2.3E-02	1.1E-02	1.4E-02	1.1E-02	1.1E-02	1.1E-02
Selenium	air	-1.2E+03	-1.6E+03	-1.7E+03	-1.8E+03	-1.8E+03	-1.4E+03	-1.3E+03	-1.5E+03	-1.3E+03	-1.3E+03	-1.4E+03	-1.5E+03
Sodium dichromate	air	-1.4E-02	-3.4E-02	-5.3E-01	-3.6E-01	-4.9E-01	-3.9E-01	-3.2E-01	-5.9E-01	-3.4E-01	-2.8E-02	-2.2E-01	-3.9E-01
Styrene	air	-1.1E-06	-1.0E-06	1.8E-03	1.7E-03	1.7E-03	5.7E-03	2.0E-03	2.0E-03	2.6E-03	2.7E-03	2.7E-03	2.5E-03
Tetrachloroethylene	air	7.7E-05	-6.6E-06	4.1E-05	6.1E-05	4.3E-05	2.9E-05	7.9E-06	2.8E-06	5.6E-06	2.0E-05	1.6E-06	6.0E-05
Thallium	air	-2.1E+01	-2.1E+01	4.6E+02	4.6E+02	4.6E+02	2.2E+02	2.2E+02	2.2E+02	6.6E+02	6.5E+02	6.6E+02	6.7E+02
Tin	air	-9.2E-01	1.5E+01	-1.4E+00	-1.2E+00	-1.5E+00	-1.3E+00	-1.2E+00	-1.3E+00	-1.2E+00	-1.1E+00	-1.3E+00	-1.3E+00
Toluene	air	-1.9E-03	-4.9E-03	1.4E-02	7.9E-03	7.8E-03	4.3E-02	3.3E-02	3.3E-02	2.3E-02	3.1E-02	3.1E-02	1.6E-02
Trichloroethylene	air	9.7E-05	1.2E-06	5.6E-05	7.8E-05	5.8E-05	4.2E-05	1.8E-05	1.2E-05	1.5E-05	3.2E-05	1.1E-05	7.8E-05
Vanadium	air	-1.0E+05	-1.8E+05	-1.3E+05	-1.9E+05	-1.2E+05	-6.9E+04	-5.5E+04	-5.3E+04	-4.7E+04	-8.0E+04	-4.7E+04	-1.0E+05
Vinyl chloride	air	-1.9E-06	-2.3E-06	-3.4E-06	-2.9E-06	-3.8E-06	-3.1E-06	-3.0E-06	-3.7E-06	-3.1E-06	-2.3E-06	-3.3E-06	-3.0E-06
Zinc	air	4.4E+03	4.4E+03	7.3E+03	6.3E+03	8.3E+03	6.6E+03	6.2E+03	7.7E+03	6.3E+03	4.4E+03	6.6E+03	6.5E+03
Acenaphthene	water	-2.4E+01	-3.8E+01	-3.9E+01	-4.7E+01	-4.4E+01	-3.0E+01	-2.6E+01	-3.1E+01	-2.8E+01	-1.9E+01	-2.9E+01	-3.1E+01
Acenaphthylene	water	-4.8E-01	-2.0E+00	-1.3E+00	-2.3E+00	-2.7E+00	-1.1E+00	-7.5E-01	-1.2E+00	-2.6E+00	-2.0E-01	-2.4E+00	-1.1E+00
Antimony	water	-3.3E+02	-3.3E+00	-3.6E+02	-8.9E+02	-4.5E+02	-3.6E+02	-3.6E+02	-3.8E+02	-3.5E+02	-3.9E+02	-5.3E+02	-3.7E+02
Arsenic	water	6.1E+03	2.3E+02	4.7E+03	5.8E+03	4.9E+03	1.9E+03	2.3E+03	5.0E+02	1.7E+03	2.5E+03	2.4E+03	2.7E+03
Arsenic, ion	water	-1.6E+04	-1.6E+04	-2.5E+04	-2.2E+04	-2.8E+04	-2.3E+04	-2.2E+04	-2.7E+04	-2.2E+04	-1.7E+04	-2.3E+04	-2.3E+04
Barite	water	-1.9E+05	-5.0E+05	-2.8E+05	-4.5E+05	5.9E+04	-1.1E+05	-7.0E+04	-6.2E+04	-1.1E+04	-8.4E+04	-7.5E+04	-1.8E+05
Barium	water	-6.4E+04	3.1E+03	-9.5E+04	-1.0E+05	-1.1E+05	-8.2E+04	-7.7E+04	-8.9E+04	-7.8E+04	-6.6E+04	-3.4E+04	-8.4E+04

Benzene	water	-2.4E+00	-2.9E+00	-3.0E+00	-3.3E+00	-3.5E+00	-2.6E+00	-2.5E+00	-2.7E+00	-2.6E+00	-2.3E+00	-2.9E+00	-2.7E+00
Benzene, chloro-	water	-9.1E-03	-6.3E-04	-4.6E-03	-1.1E-02	-9.0E-03	-1.2E-02	-1.1E-02	-1.3E-02	-1.2E-02	-5.2E-02	-1.1E-02	-2.5E-02
Beryllium	water	-2.1E+05	-2.2E+05	-3.0E+05	-2.6E+05	-3.4E+05	-2.8E+05	-2.8E+05	-3.2E+05	-2.7E+05	-2.4E+05	-1.6E+05	-2.8E+05
Cadmium	water	3.2E+03	8.5E+03	9.5E+02	1.8E+03	1.4E+03	5.4E+02	2.8E+02	-1.9E+01	2.6E+02	4.7E+02	2.3E+03	1.3E+03
Cadmium, ion	water	-3.9E+03	-4.1E+03	-3.9E+03	-4.8E+03	-4.9E+03	-4.3E+03	-4.2E+03	-4.3E+03	-6.0E+03	-5.5E+03	-5.7E+03	-4.7E+03
Chlorinated solvents, unspecified	water	-8.7E-02	-7.0E-02	-9.8E-02	-1.5E-01	-1.4E-01	-1.2E-01	-1.1E-01	-1.4E-01	-1.2E-01	-1.9E-01	-1.4E-01	-1.5E-01
Chloroform [Trichloromethane]	water	-2.1E-06	1.6E-07	-8.8E-07	-2.6E-06	-2.1E-06	-2.8E-06	-2.7E-06	-3.1E-06	-2.9E-06	-1.4E-05	-2.6E-06	-6.4E-06
Chromium	water	2.6E+02	1.5E+02	1.1E+02	2.1E+02	1.4E+02	1.0E+02	7.7E+01	8.0E+01	1.0E+02	7.1E+01	2.0E+02	1.2E+02
Chromium VI	water	-1.4E+04	-1.3E+04	-2.2E+04	-1.9E+04	-2.4E+04	-2.0E+04	-1.8E+04	-2.3E+04	-1.9E+04	-1.4E+04	-2.0E+04	-2.0E+04
Cobalt	water	-6.1E+04	-4.6E+04	-9.4E+04	-7.4E+04	-9.5E+04	-8.5E+04	-7.8E+04	-9.2E+04	-8.1E+04	-6.8E+04	4.9E+04	-8.9E+04
Copper	water	4.3E+04	1.8E+05	8.2E+03	2.9E+04	1.1E+04	2.7E+04	1.4E+04	1.9E+04	2.4E+04	2.2E+04	5.1E+04	2.8E+04
Copper, ion	water	5.2E+05	5.2E+05	5.1E+05	4.9E+05	5.9E+05	5.1E+05	5.2E+05	5.1E+05	5.1E+05	5.0E+05	5.7E+05	5.1E+05
Di(2-ethylhexyl)phthalate (DEHP)	water	1.5E+01	3.3E-01	6.5E+00	8.0E+00	8.2E+00	3.2E+00	1.9E+00	1.6E+00	1.5E+00	3.9E+00	1.9E+00	8.9E+00
Dichloromethane	water	-1.7E-02	-3.2E-02	-2.9E-02	-3.5E-02	-1.2E-02	-2.2E-02	-1.8E-02	-2.2E-02	-1.7E-02	-1.4E-02	-2.1E-02	-2.3E-02
Dichromate	water	-1.3E+01	-1.3E+01	-2.0E+01	-1.8E+01	-2.3E+01	-1.8E+01	-1.7E+01	-2.1E+01	-1.7E+01	-1.3E+01	-1.8E+01	-1.8E+01
Ethane, 1,1,1-trichloro-, HCFC-140	water	-4.2E-09	-5.0E-09	-4.1E-09	-4.9E-09	-5.6E-09	-4.5E-09	-4.4E-09	-4.6E-09	-6.9E-09	-4.2E-09	-6.7E-09	-4.5E-09
Ethene	water	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.1E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-1.7E-01	-2.0E-01	-1.7E-01
Ethene, chloro-	water	-2.4E-04	-2.5E-04	-3.9E-04	-3.4E-04	-4.4E-04	-3.5E-04	-3.3E-04	-4.0E-04	-3.3E-04	-2.6E-04	-3.5E-04	-3.5E-04
Ethene, tetrachloro-	water	4.6E-08	3.9E-08	4.8E-08	4.5E-08	4.2E-08	4.5E-08	4.5E-08	4.5E-08	3.9E-08	4.6E-08	4.2E-08	4.5E-08
Ethene, trichloro-	water	9.6E-04	2.2E-05	4.8E-04	8.9E-04	7.3E-04	2.8E-04	2.2E-04	2.0E-04	2.5E-04	4.0E-04	1.2E-04	5.3E-04
Ethylbenzene	water	-1.7E+00	-2.7E+00	-2.8E+00	-3.3E+00	-3.1E+00	-2.1E+00	-1.8E+00	-2.2E+00	-2.0E+00	-1.4E+00	-2.1E+00	-2.2E+00
Ethylene dichloride	water	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.9E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.3E-01	-2.6E-01	-2.8E-01	-2.4E-01
Ethylene oxide	water	-4.4E-01	-4.3E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.4E-01	-4.6E-01	-4.4E-01	-4.5E-01
Formaldehyde	water	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.6E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-3.7E+03	-4.4E+03	-3.7E+03
Fungicides, unspecified	water	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.7E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	4.6E-03	5.5E-03	4.6E-03
Herbicides, unspecified	water	-3.4E-05	-8.5E-07	-1.6E-05	-4.1E-05	-3.3E-05	-4.4E-05	-4.2E-05	-4.8E-05	-4.4E-05	-2.0E-04	-4.1E-05	-9.5E-05
Insecticides, unspecified	water	8.7E+00	8.7E+00	8.7E+00	8.7E+00	1.1E+01	8.7E+00	8.7E+00	8.7E+00	8.7E+00	8.6E+00	1.0E+01	8.7E+00
Lead	water	6.6E+02	6.4E+02	4.4E+02	5.1E+02	4.9E+02	6.6E+02	4.0E+02	3.5E+02	3.6E+02	3.7E+02	1.3E+03	4.4E+02
Mercury	water	-1.2E+02	-3.7E+02	-2.2E+02	-6.7E+01	-2.6E+02	-3.6E+02	-3.2E+02	-3.7E+02	-3.9E+02	-4.1E+02	7.8E+01	-3.6E+02
Metals (unspecified)	water	-1.2E+02	-1.2E+02	-1.1E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02	-1.2E+02

Molybdenum	water	-6.1E+03	2.8E+04	-7.5E+03	-6.6E+03	-8.3E+03	-7.3E+03	-7.3E+03	-7.7E+03	-6.7E+03	-6.5E+03	-8.0E+03	-7.1E+03
m-Xylene	water	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02	1.1E-02
Nickel	water	1.7E+05	5.2E+04	7.6E+04	1.4E+05	7.5E+04	1.0E+05	8.3E+04	7.9E+04	9.6E+04	1.1E+05	4.9E+05	1.1E+05
Nickel, ion	water	-9.7E+03	2.4E+03	-3.8E+04	-4.9E+04	4.0E+04	-1.9E+03	1.8E+04	2.8E+04	1.3E+04	-2.9E+04	2.7E+04	-3.6E+04
o-Xylene	water	3.8E-04	3.8E-04	6.1E-04	5.3E-04	6.9E-04	5.5E-04	5.1E-04	6.3E-04	5.2E-04	3.8E-04	5.5E-04	5.4E-04
PAH, polycyclic aromatic hydrocarbons	water	-2.1E+04	-3.2E+04	-3.4E+04	-4.1E+04	-3.8E+04	-2.6E+04	-2.2E+04	-2.6E+04	-2.6E+04	-1.6E+04	-2.6E+04	-2.7E+04
Phenol	water	-3.5E+03	-5.4E+03	-5.4E+03	-7.3E+03	-6.1E+03	-4.4E+03	-3.9E+03	-4.6E+03	-4.2E+03	-3.1E+03	-5.0E+03	-4.4E+03
Phthalate, dibutyl-	water	2.1E-06	6.5E-07	2.4E-06	1.3E-06	1.2E-07	1.6E-06	1.8E-06	1.5E-06	-1.7E-06	2.0E-06	-9.8E-07	1.7E-06
Propylene oxide	water	2.6E+00	2.6E+00	2.4E+00	2.4E+00	3.0E+00	4.5E+00	4.7E+00	2.3E+00	2.9E+00	2.3E+00	2.4E+00	2.4E+00
Selenium	water	-4.5E+04	-4.5E+04	-7.0E+04	-6.1E+04	-7.9E+04	-6.4E+04	-6.1E+04	-7.4E+04	-6.1E+04	-4.6E+04	-5.9E+04	-6.4E+04
Thallium	water	-1.8E+03	-3.2E+03	-3.1E+03	-3.8E+03	-3.0E+03	-2.0E+03	-1.7E+03	-2.0E+03	-1.5E+03	-1.6E+03	-1.6E+03	-2.4E+03
Tin, ion	water	1.9E+02	1.9E+02	1.7E+02	1.7E+02	2.0E+02	1.8E+02	1.8E+02	1.7E+02	1.8E+02	1.8E+02	3.2E+02	1.8E+02
Toluene	water	-4.5E+00	-7.4E+00	-7.6E+00	-9.2E+00	-8.5E+00	-5.9E+00	-5.1E+00	-6.1E+00	-5.6E+00	-3.8E+00	-5.8E+00	-6.0E+00
Tributyltin compounds	water	-2.9E+05	-3.3E+05	-4.6E+05	-4.2E+05	-5.2E+05	-4.0E+05	-3.8E+05	-4.5E+05	-3.9E+05	-3.1E+05	-4.1E+05	-4.1E+05
Vanadium, ion	water	-9.3E+06	-9.3E+06	-1.5E+07	-1.3E+07	-1.7E+07	-1.4E+07	-1.3E+07	-1.6E+07	-1.3E+07	-9.7E+06	-1.4E+07	-1.4E+07
Xylene - all isomers [Dimethylbenzene]	water	-7.4E+00	-1.2E+01	-1.2E+01	-1.5E+01	-1.4E+01	-9.5E+00	-8.2E+00	-9.9E+00	-9.0E+00	-6.1E+00	-9.4E+00	-9.8E+00
Zinc	water	5.7E+04	-1.5E+04	5.3E+03	2.8E+04	2.7E+04	3.7E+04	1.5E+04	1.9E+04	2.7E+04	2.2E+04	1.3E+05	2.6E+04
2,4-D	soil	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.1E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	3.3E+01	4.0E+01	3.3E+01
Antimony	soil	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.1E-03	1.9E-03	2.0E-03	2.0E-03
Arsenic	soil	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	5.2E+03	4.6E+04	5.2E+03	3.0E+04	5.2E+03
Atrazine	soil	-1.0E-02	-9.3E-03	-1.0E-02	-1.2E-02	-1.3E-02	-1.1E-02	-1.1E-02	-1.2E-02	-1.6E-02	-1.7E-02	-1.5E-02	-1.3E-02
Barium	soil	-3.9E+03	-7.5E+03	-6.6E+03	-8.1E+03	-2.7E+03	-5.0E+03	-4.2E+03	-5.1E+03	-4.0E+03	-3.2E+03	-4.8E+03	-5.2E+03
Bentazone	soil	1.0E+00	1.1E+00	1.0E+00	1.0E+00	1.3E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.2E+00	1.0E+00
Cadmium	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	2.0E+04	1.3E+03	1.3E+04	1.3E+03
Chlorothalonil	soil	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01	6.0E+01
Chromium	soil	5.3E+02	5.3E+02	5.3E+02	5.3E+02	5.3E+02	5.3E+02	5.3E+02	5.3E+02	5.0E+03	5.3E+02	3.2E+03	5.3E+02
Chromium VI	soil	-9.1E+02	-9.3E+02	-1.4E+03	-1.2E+03	-1.6E+03	-1.3E+03	-1.2E+03	-1.5E+03	-1.2E+03	-9.2E+02	-1.3E+03	-1.3E+03
Cobalt	soil	-4.5E+01	-4.7E+01	-4.6E+01	-4.7E+01	-5.4E+01	-4.5E+01	-4.5E+01	-4.5E+01	-4.4E+01	-4.8E+01	-5.1E+01	-4.6E+01
Copper	soil	-1.9E+05	-1.9E+05	-2.0E+05	-1.9E+05	-2.0E+05	-2.0E+05	-1.9E+05	-2.0E+05	1.3E+06	-1.9E+05	7.2E+05	-2.0E+05
Cypermethrin	soil	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.4E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.3E+05	1.1E+05

Dinoseb	soil	-4.7E+00	-4.8E+00	-1.2E+01	-6.4E+00	-6.2E+00	-6.0E+00	-6.2E+00	-6.4E+00	-7.4E+00	-5.8E+00	-1.1E+01	-5.1E+00
Glyphosate	soil	1.8E+01	1.8E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	1.7E+01	2.1E+01	1.7E+01
Lead	soil	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.7E+03	3.2E+04	3.7E+03	2.1E+04	3.7E+03
Linuron	soil	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.6E+03	1.3E+03
Mercury	soil	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	7.2E+02	6.8E+03	7.2E+02	4.4E+03	7.2E+02
Metazachlor	soil	1.0E+01	5.7E+00	1.0E+01	1.0E+01	9.9E+00	1.0E+01	1.0E+01	1.0E+01	9.4E+00	1.0E+01	9.5E+00	1.0E+01
Metolachlor	soil	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.2E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	2.6E+04	3.1E+04	2.6E+04
Molybdenum	soil	-1.4E+00	-1.5E+00	-1.5E+00	-1.5E+00	-1.7E+00	-1.5E+00	-1.4E+00	-1.5E+00	-1.4E+00	-1.7E+00	-1.6E+00	-1.5E+00
Nickel	soil	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.3E+05	1.1E+06	1.3E+05	7.4E+05	1.3E+05
Pirimicarb	soil	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.5E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.0E+01	2.4E+01	2.0E+01
Selenium	soil	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04
Thallium	soil	5.8E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.8E-05	5.8E-05	5.7E-05	5.8E-05	5.7E-05	5.8E-05
Tin	soil	-8.4E-04	2.2E-03	-8.6E-04	-3.6E-03	-4.9E-03	-4.2E-03	-3.6E-03	-5.8E-03	-3.5E-03	-2.5E-02	-2.8E-03	-1.2E-02
Vanadium	soil	-2.6E+02	-2.8E+02	-2.7E+02	-2.8E+02	-3.2E+02	-2.6E+02	-2.6E+02	-2.6E+02	-2.6E+02	-2.7E+02	-3.0E+02	-2.7E+02
Zinc	soil	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	4.5E+04	5.1E+05	4.5E+04	3.3E+05	4.5E+04