Environmental benefits of recycling

An international review of life cycle comparisons for key materials in the UK recycling sector

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Foreword

A recurring theme in the debates that surround waste and resources management is the extent to which the recycling of materials offers genuine benefits to the environment. Often, critics of the policy drive towards greater recycling assert that the act of recycling may in fact have little or no benefit to the environment, suggesting that more energy may be used in getting materials to the recycling facility than is saved by the process of recycling.

In order to inform this debate more fully, WRAP (the Waste & Resources Action Programme) commissioned a major international research project from the Technical University of Denmark (IPU) and the Danish Topic Centre on Waste. The Danish team of experts, who have worked closely on the development of life-cycle thinking to inform future European waste strategies, conducted a comprehensive international review of existing life cycle analysis (LCA) projects that have used ISO standard methodologies to evaluate the impact on the environment of managing key materials in different ways – through recycling, incineration or landfill.

This study is the largest and most comprehensive international review of LCA work on key materials that are often collected for recycling – paper/cardboard, plastics, aluminium, steel, glass, wood and aggregates. Of several hundred studies that were screened, 55 'state-of-the-art' LCAs were selected for detailed review, comprising over 200 different scenarios, each one an LCA in its own right.

The review recognises that a key issue with LCA work on complex products and waste management systems is that it often produces contradictory findings in attempting to analyse similar systems. This is due to differences in the assumptions made, the system boundaries that are set and the interpretation of the results.

By conducting a large scale international review, and using rigorous criteria to 'sift out' those studies with less robust methodology and assumptions, the result is a far more objective review of the environmental impacts of different waste management systems for those key materials than any one individual study can deliver.

The results are clear. Across the board, most studies show that recycling offers more environmental benefits and lower environmental impacts than other waste management options.

Further analysis by WRAP of the research findings has provided an assessment of the relative greenhouse gas savings associated with current UK levels of recycling for paper/cardboard, glass, plastics, aluminium and steel.

Again, the results are clear and positive. The UK's current recycling of those materials saves between 10-15 million tonnes of CO_2 equivalents per year compared to applying the current mix of landfill and incineration with energy recovery to the same materials. This is equivalent to about 10% of the annual CO_2 emissions from the transport sector, and equates to taking 3.5 million cars off UK roads.

The message for policy makers and practitioners is unequivocal. Recycling is good for the environment, saves energy, reduces raw material extraction and combats climate change. It has a vital role to play as waste and resource strategies are reviewed to meet the challenges posed by European Directives, as well as in moving the UK towards more sustainable patterns of consumption and production and in combating climate change by reducing greenhouse gas emissions.

The environmental benefits demonstrated by this study show that it is time for recycling to take its rightful place at the heart of sustainable waste management and resource efficiency, and reinforce its clear contribution to reducing greenhouse gas emissions.

Ray Georgeson MBE
Director of Policy and Evaluation
WRAP (the Waste & Resources Action Programme)
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Executive Summary

Life Cycle Assessment (LCA) is one of the most widely used and internationally accepted methods for the evaluation of the environmental impacts of products and systems. An LCA is a calculation of the environmental burden of a material, product or service during its lifetime.

LCA has been used in the last decade to compare the environmental impacts of different options for the handling of waste. However, the application of LCA to such complex systems presents significant challenges, the most important being whether or not the interactions between a waste system with its surrounding technosphere have been properly characterised. Different assumptions around such interactions have often resulted in LCAs which apparently analyse the same material system but produce very different conclusions. A key objective of the present review was therefore to build a greater understanding of the critical factors that determine environmental preferences between waste management options, taking into account overall life cycle impacts and underlying assumptions.

With the purpose of identifying state-of-the-art research on the environmental impacts of waste management, an extensive search has been conducted for seven material categories of key significance to the recycling sector: paper/cardboard, plastics, glass, wood, steel, aluminium and aggregates. Preference has been given to studies following scientifically valid and if possible standardised assessment methodologies, preferably LCA methods meeting the standards of the International Organisation for Standardisation.

The international literature search contained three main elements:

1) targeted approach to LCA institutions and experts worldwide;
2) a broad search of the scientific literature; and
3) an international Internet search via search engines and homepages of relevant institutions (mainly national Environmental Protection Agencies).

The search resulted in the identification of several hundred potentially relevant references which were then sifted and short-listed for a more detailed review. The main criteria for inclusion were: that it should be a holistic environmental study, preferably an LCA, meeting a set of methodological quality criteria, that its results should be unambiguously ascribable to the material in question, and that it should include a comparison of two or more options for the waste management phase. In total, 55 studies were judged to represent the state-of-the-art knowledge on the environmental aspects of waste management. Table ES 1 summarises the number of studies evaluated and selected by material.

Table ES 1: Number of studies evaluated and number selected for detailed review by material.

Material	Number of studies evaluated	Number of studies used	Number of scenarios identified
Glass	19	11	25
Wood	29	3	7
Paper and cardboard	108	9	63
Plastics	42	10	60
Aluminium	19	11	20
Steel	31	9	20
Aggregates	24	2	6

Each of the reviewed studies was a comparison between two or more waste management options. Each study comprised two or more scenarios of varying system boundary conditions and assumptions, each one being an LCA in its own right. The final set of studies related to a wide range of different geographical areas, including North America, Europe and the Antipodes.

Across the 55 studies the assumptions that were found to be most critical to the results were those that related to the interdependency between waste handling systems and the energy system of the surrounding technosphere, including:

- **the type of energy used for the manufacture of primary materials;**
- **the type of energy used for the manufacture of secondary products from recycled materials;**
- **the type of recycling process applied.**

The review has provided a systematic means of highlighting system boundary conditions that were significant to LCA outcomes. For six of the materials these can be condensed into the 16 key issues shown in Table ES 2, relating to different life cycle stages. For paper and cardboard, a slightly different set of key boundary issues have been identified in Table ES 3.

Table ES 2: Key system boundary issues in the LCAs excluding paper and cardboard

Material production	Virgin material	
	1	Material marginal. Average or specific? Which?
	2	Electricity marginal: which? Hydro, biomass, coal, gas, oil, other?
	3	Steam marginal: which? Biomass, coal, gas, oil, other?
	4	Co-products dealt with? If yes: by allocation? By system expansion?
	Secondary material	
	5	Material marginal. Average or specific? Which?
	6	Electricity marginal: which? Hydro, biomass, coal, gas, oil, other?
	7	Steam marginal: which? Biomass, coal, gas, oil, other?
	8	Co-products dealt with? If yes: by allocation? By system expansion?
Ante-material recovery	9	Product dependent material recovery included? Yes/no
	10	Type of product dependent material recovery
Material disposal	11	Disposal comparison e.g.: recycling vs incineration
	12	Emissions from landfill included? Considered/no information
	13	Energy from incineration substitutes heat? Considered/no information
	14	Energy from incineration substitutes electricity? Considered/no information
	15	Alternative use of incineration capacity included? Considered/no information
	16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0 5 or other)

Table ES 3: Key system boundary issues in the LCAs of paper and cardboard

Raw materials/ forestry	1	Alternative use of land/wood included?
	2	Saved wood used for energy?
	3	Wood marginal
Paper production	Virgin paper	
	4	– Electricity marginal
	5	– Steam marginal
	Recovered paper	
	6	– Electricity marginal
	7	– Steam marginal
	8	Energy export from virgin paper included?
Disposal/energy recovery	9	Which is the main alternative to recycling: incineration or landfilling?
	10	Emissions from landfill included?
	11	Energy from incineration substitutes heat?
	12	Energy from incineration substitutes electricity?
	13	Alternative use of incineration & landfilling capacity included?
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)
	15	Handling of rejects and de-linking waste from paper recovery included?

The purpose of a comparative LCA is to reflect the environmental consequences of choosing one alternative over another. One of the requirements of the most recent LCA guidelines is that the processes and systems to be included are the marginal ones (those responding to a change in demand). In the energy sector, the concept of the marginal electricity is well known, being the electricity production that is turned on or off as a response to changes in demand. However, the review found that many LCAs still used the average energy production mix instead of marginal energy sources. Inevitably, such choices and inconsistencies can greatly influence the energy-related impact results of an LCA study.

The review has highlighted important differences that resulted from the way in which different LCAs have been constructed and these differences must be considered when drawing more general conclusions from the review. However, Table ES 4 shows that from 188 scenarios that included recycling, the overwhelming majority of them (83%) favoured recycling over either landfill or incineration.

The environmental impact categories that featured in the review included energy use, resource consumption, global warming potential, other energy-related impacts, toxicity, waste generation and other impacts (such as on land use or biodiversity). The study developed a method for dealing with the complexities of LCA outputs through the use of summary graphs to represent the findings across different scenarios and environmental impact categories. Figures ES 1-7 display results for greenhouse gas impacts for the seven materials, using the following method.

Table ES 4: Overall environmental preference of waste management options across all reviewed scenarios

	Recycling v Incineration			Recycling v Landfill		
Material	Recycling	Incineration	No preference	Recycling	Landfill	No preference
Paper	22	6	9	12	0	1
Glass	8	0	1	14	2	0
Plastics	32	8	2	15	0	0
Aluminium	10	1	0	7	0	0
Steel	8	1	0	11	0	0
Wood						
Aggregates				6	0	0
Totals	80	16	12	65	2	1

	Incineration v Landfill			Recycling v Mixed			Grand Total
Material	Incineration	Landfill	No preference	Recycling	Mixed	No preference	
Paper	1	0	0	12	0	0	63
Glass							25
Plastics	2	0	1				60
Aluminium	2	0	0				20
Steel							
Wood	7	0	0				7
Aggregates							6
Totals	12	0	1	12	0	0	201

In order to explore the relative environmental benefits of whole life scenarios containing different waste management options, each scenario was represented by a numbered box, the first digit indicating the number of the study and second, the scenario within it. These were then placed along a scale of relative environmental burden, indicating which option had either more or less environmental burden than the other. If one scenario came up with a value within the same range as another, the boxes were then stacked in columns, indicating the frequency distribution of the results across the entire review for that particular material, impact category and waste management comparison.

Some of the reviewed studies only covered part of the life cycle, and could not be represented alongside whole life cycle scenarios. Such cases were placed off the scale of the graphs as a qualitative indication of the relative environmental impact of the comparison covered. These were indicated by boxes with dashed outlines placed off the scale on either the left or right hand side of the diagram, depending on the environmental preference.

Particular attention was given to quantification of the greenhouse gas implications of different scenarios, measured as CO_2-equivalents. In line with the overall findings, it was concluded that for paper/cardboard, plastics, glass, steel, aluminium and aggregates there was generally a greenhouse gas emission saving from recycling compared with either landfill or incineration. Figures ES 1-7 summarise these findings using the graphing method described above. For wood, no credible comparative scenarios could be found that included recycling as an end of life option, so Figure ES 4 relates to three LCAs that compared incineration with landfill.

In the case of glass, the review highlighted the importance of the type of recycling in determining the relative advantage compared with either landfilling or incineration. Closed loop glass recycling was found to be preferable to both incineration and landfilling in environmental terms, while certain types of ‘open loop’ glass recycling, such as glass into aggregates, appeared to be more marginal or even disadvantageous. However, this conclusion was based on a single study, so wider application to other materials would be misleading.

The review identified a number of significant gaps within the LCA literature and has also indicated boundary conditions and system assumptions should be given more attention in future work. The generation of more complete information on the life cycle wide environmental implications of alternative open loop recycling options for a range of materials was a case-in-point, as was the need for comparative LCAs for wood recycling against alternative options.

Figure ES 1: Paper and cardboard comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options

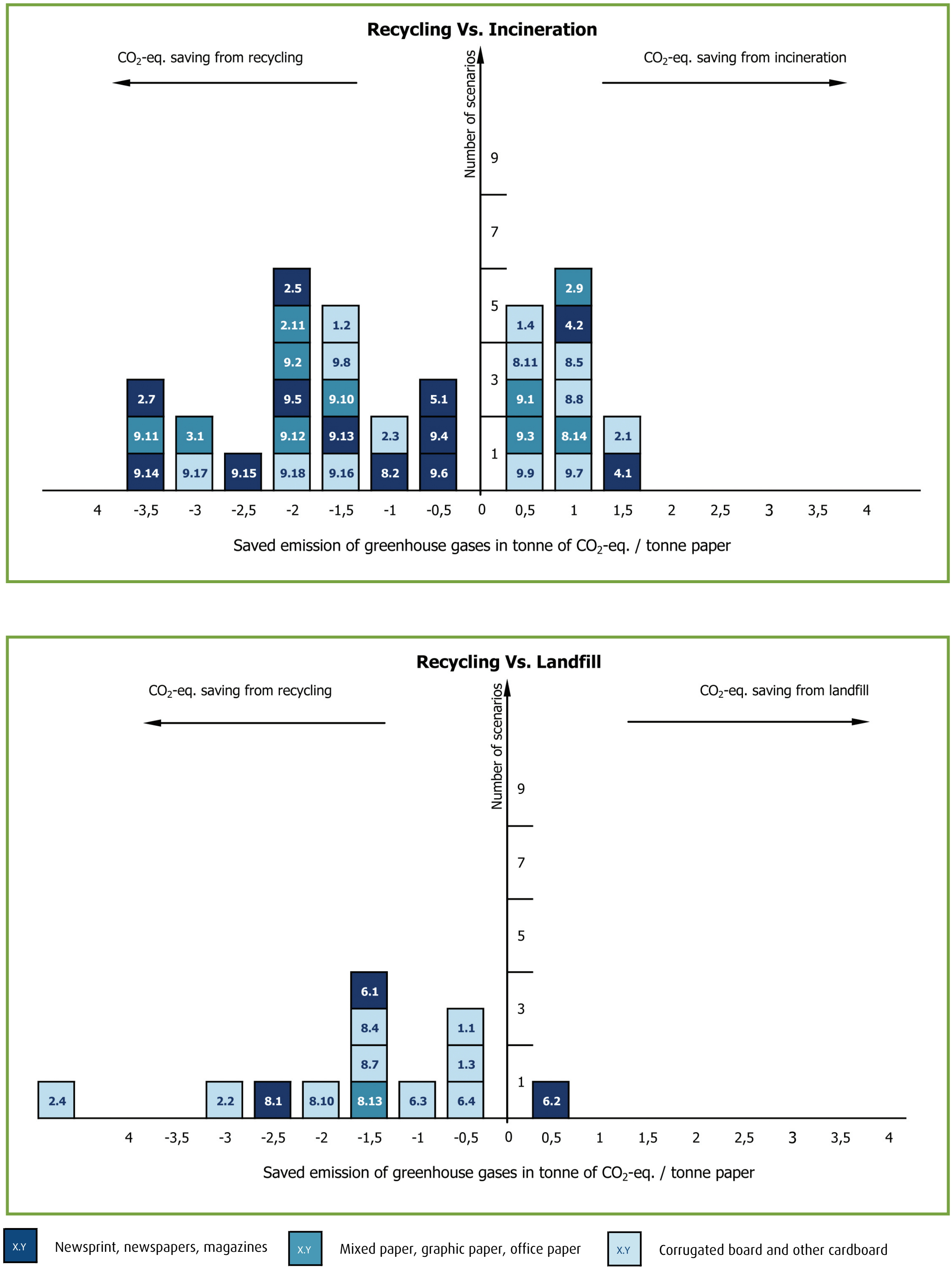
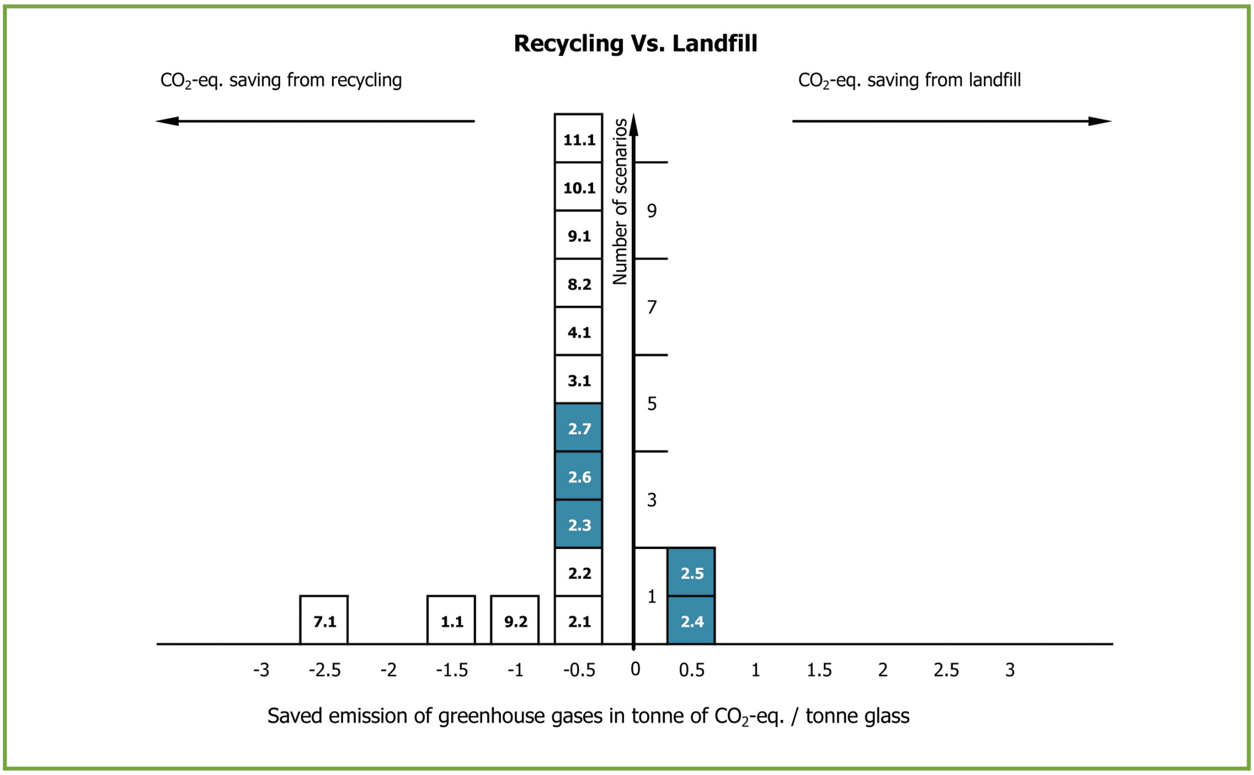
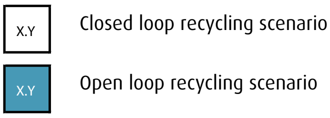


Figure ES 2: **Glass** comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options





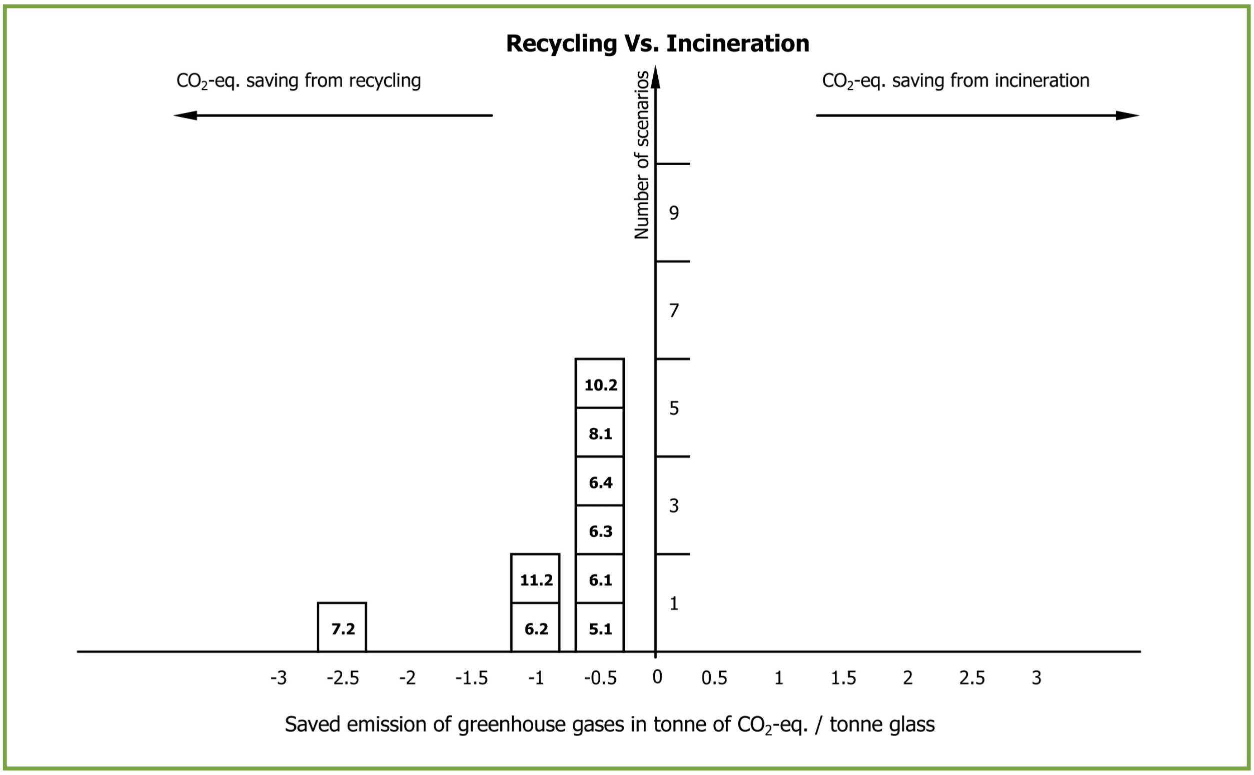


Figure ES 3: Plastics comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options

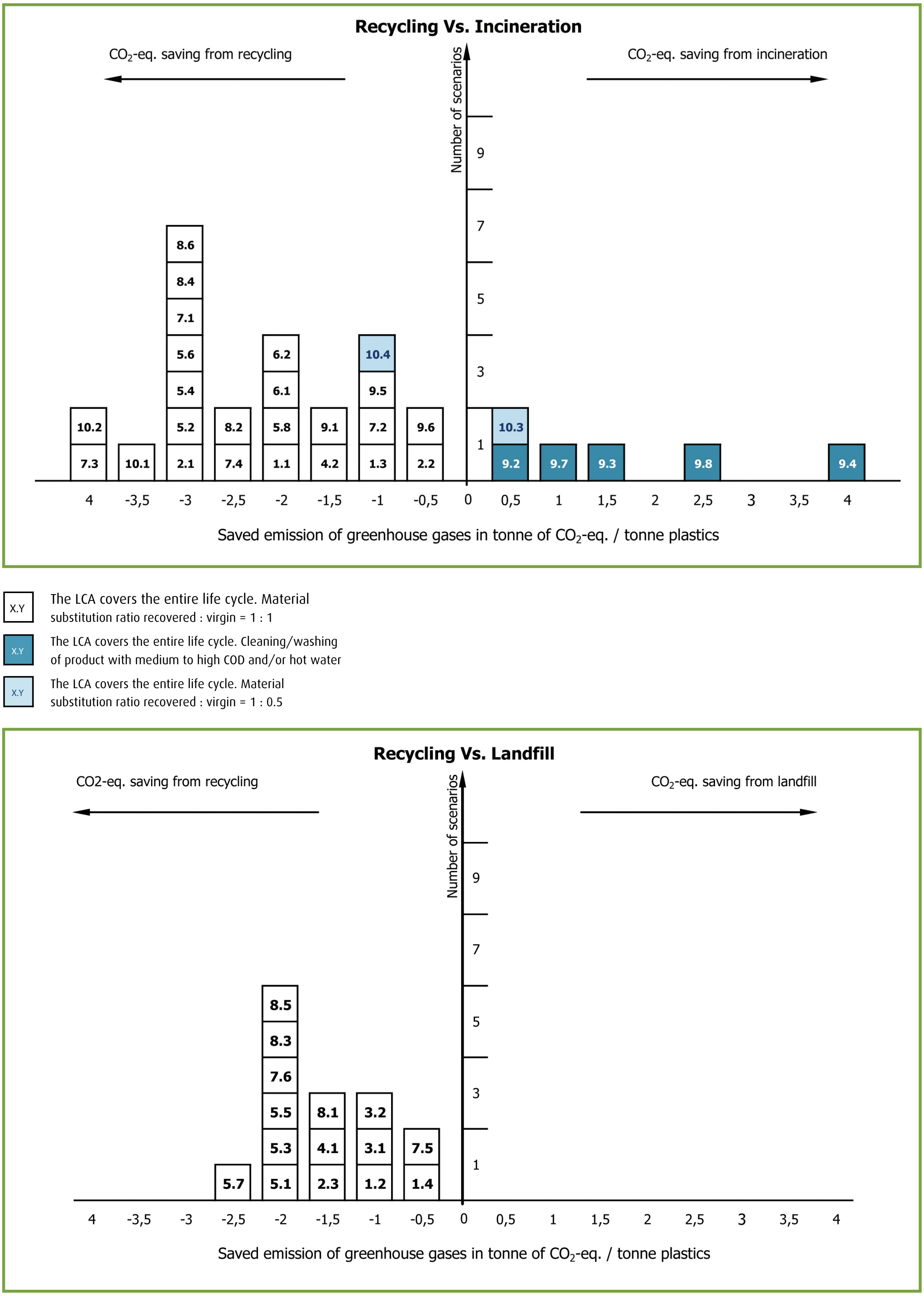


Figure ES 4: **Wood** comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options

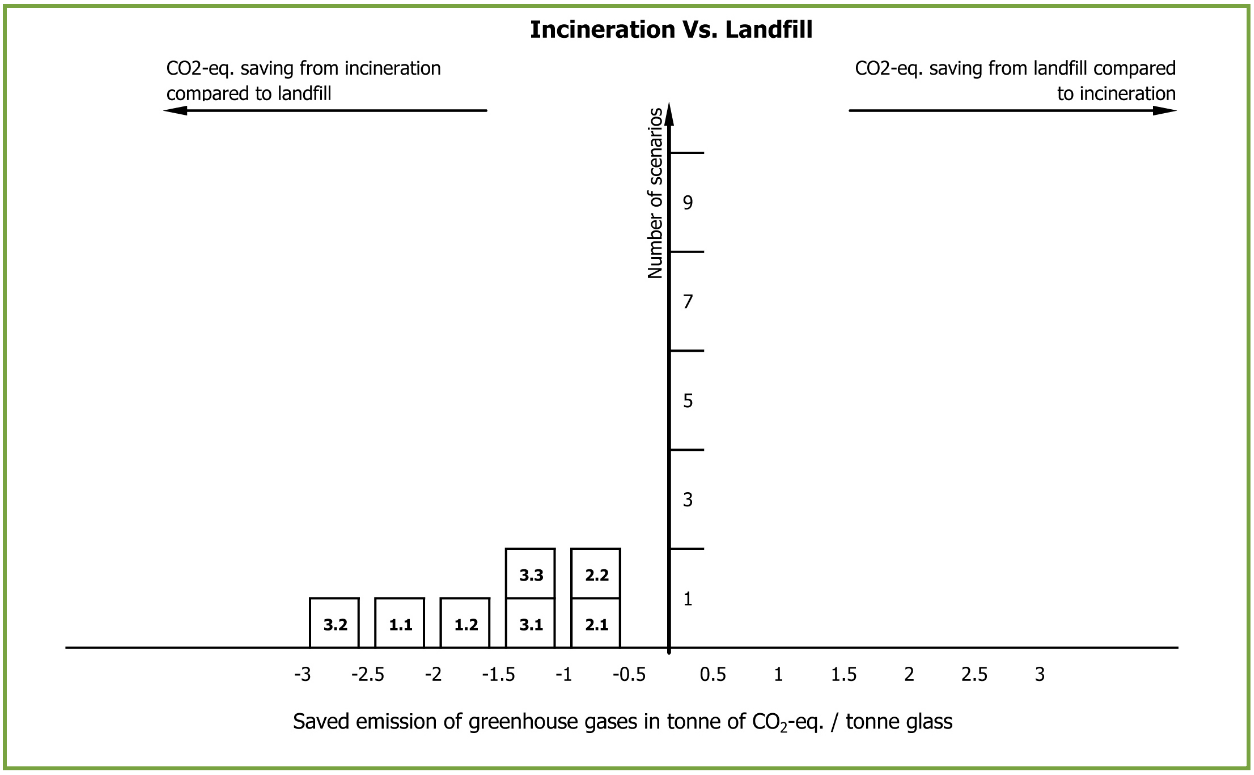


Figure ES 5: **Aggregates** comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options

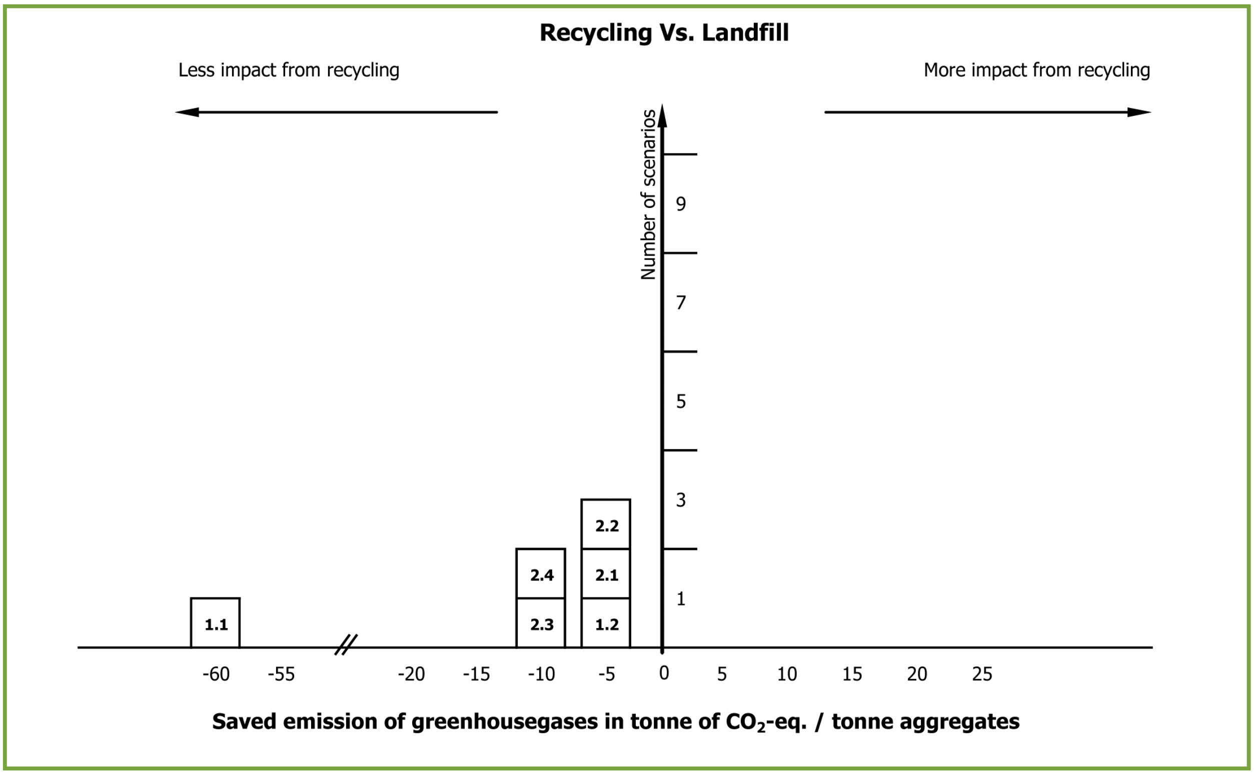
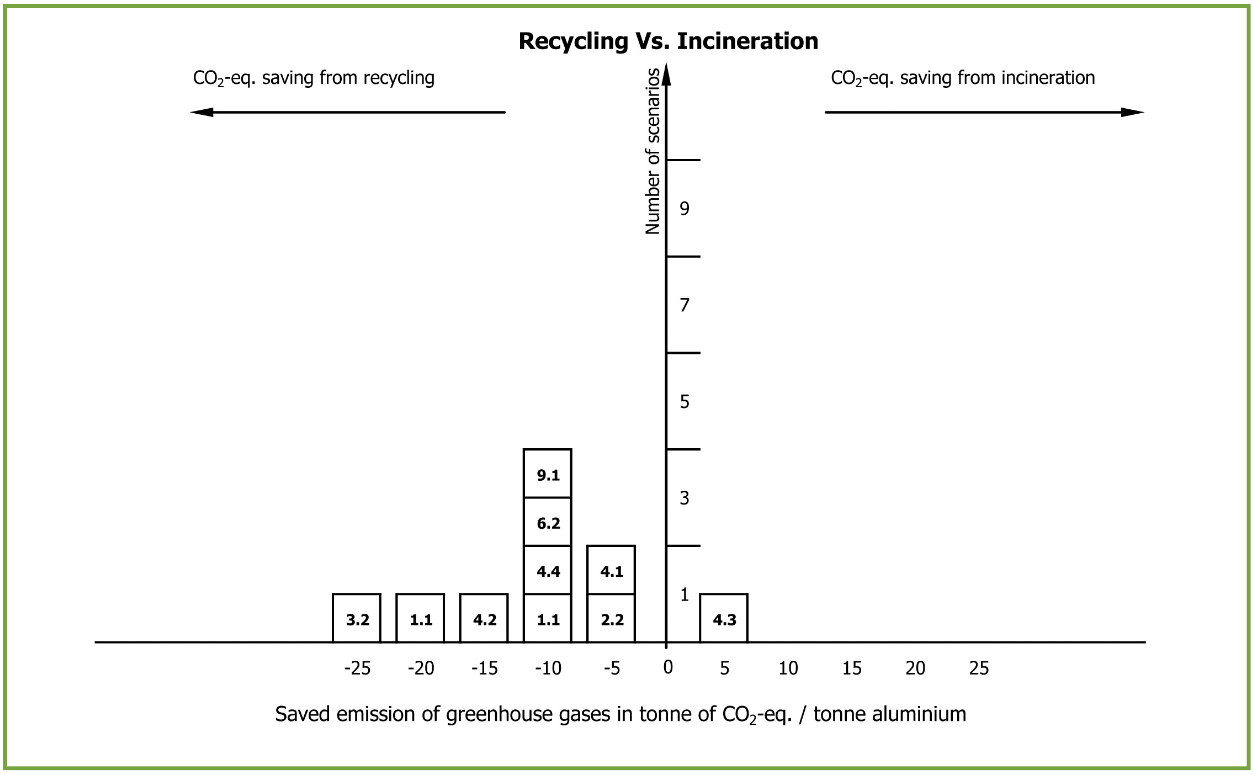


Figure ES 6: Aluminium comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options



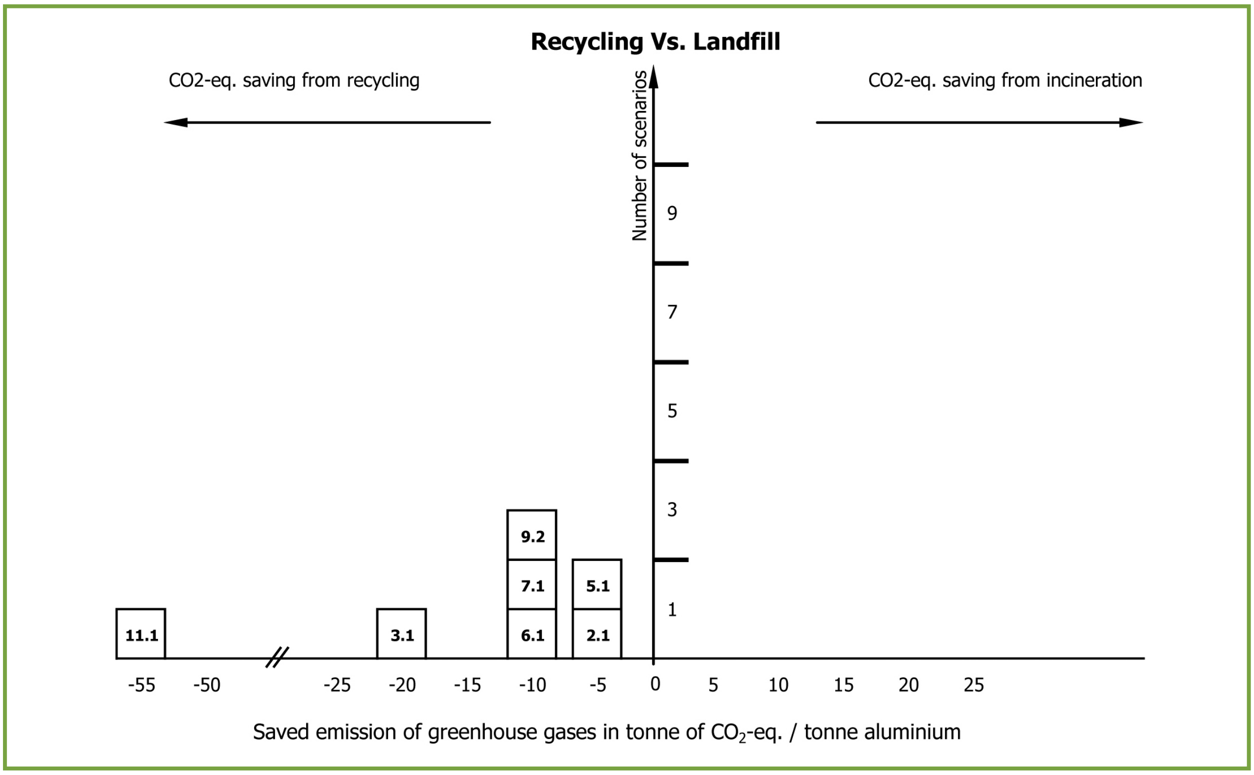
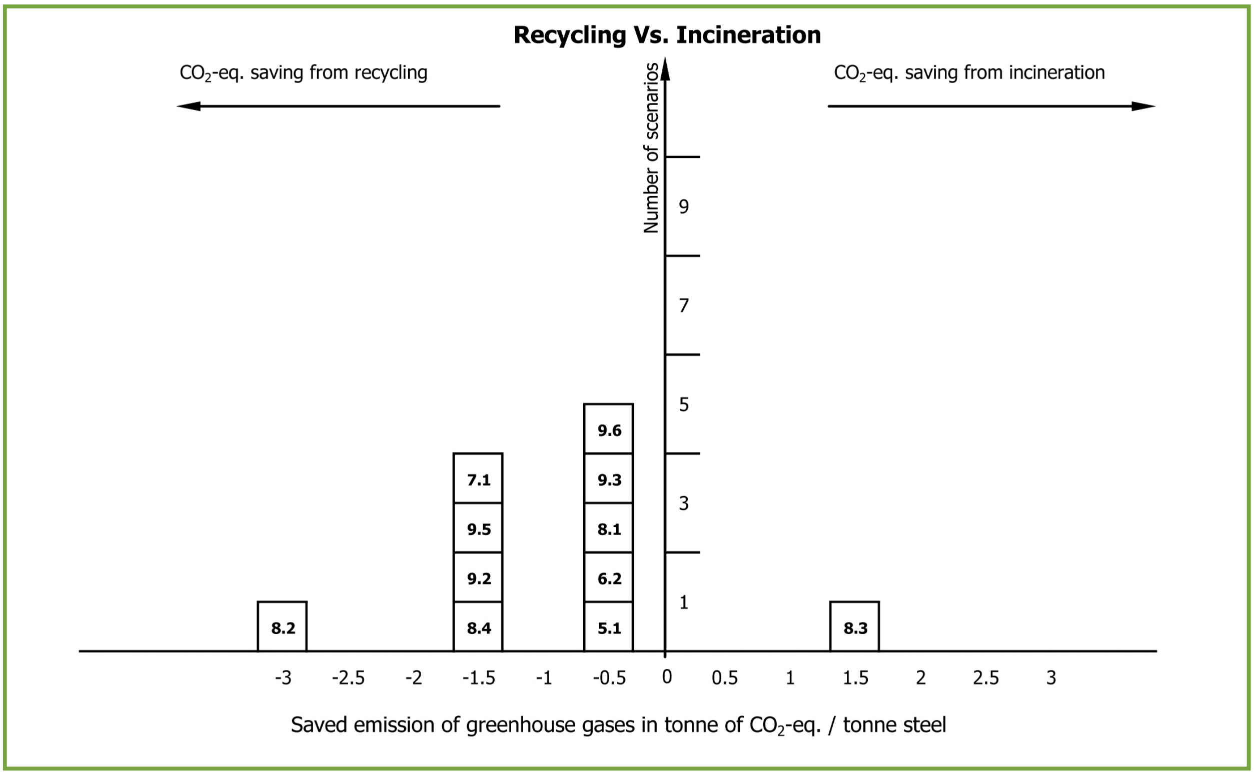
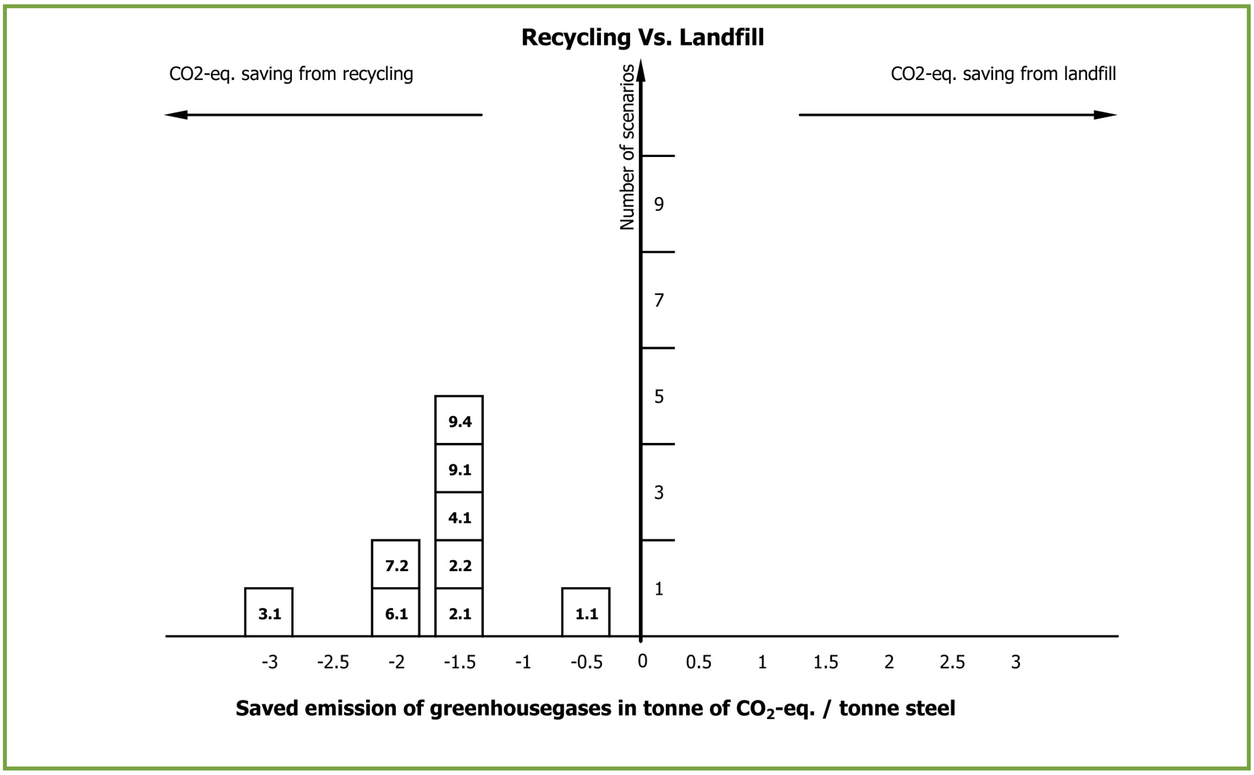


Figure ES 7: Steel comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options





For further information please contact WRAP at:

WRAP
The Old Academy
21 Horse Fair
Banbury
Oxon
OX16 0AH

Telephone: 01295 819900
Website: www.wrap.org.uk
Helpline: 0808 100 2040
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