Report

Final Report

The Scottish Carbon Metric

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Zero Waste Scotland is the new programme created by the Scottish Government to support delivery of its Zero Waste Plan.

It will integrate the activities of WRAP Scotland, Waste Aware Scotland, Keep Scotland Tidy, Remade Scotland, Envirowise in Scotland, NISP in Scotland, and some programmes delivered by the Community Recycling Network for Scotland.

Our vision is a world without waste, where resources are used sustainably. Find out more at www.zerowastescotland.org.uk

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Executive summary

This report documents the technical background and methodology underpinning the creation of the Carbon Metric for Scotland. The Carbon Metric allows strategic decisions to be made about the end of life choices for materials and products based on their environmental impact, measured in terms of greenhouse gas emissions. It is designed to support the prioritisation of waste management options and materials in order to meet the Zero Waste Plan targets.

In 2010, the Scottish Government published the Zero Waste Plan. This plan, as required by the EU Waste Framework Directive, describes the drive to reduce the environmental impact of waste through the application of the waste hierarchy. The Carbon Metric has been created to support this requirement by allowing environmental impacts of alternative waste management options for materials and products to be considered alongside tonnage when making strategic decisions about waste. The tracking of progress towards targets set out in the Zero Waste Plan for recycling will now take into account the Carbon Metric, and therefore environmental impact, of the waste of materials and products created in Scotland.

The Carbon Metric has been designed by the Scottish Government and Zero Waste Scotland with input from steering committee formed from the experts belonging to the Chartered Institution of Waste Management. The methodology and selection of data sources have been reviewed by the Carbon Trust Advisory Services. The accompanying Guidance Report and Carbon Metric Calculator are intended to assist the application of the Carbon Metric by users throughout Scotland. This report provides the technical background and methodology behind the creation of the Carbon Metric, giving information on the scope, data and assumptions made.

The Carbon Metric takes a Life Cycle approach to measuring the environmental impact of a range of materials and products in a systematic and holistic manner, considering emissions of a range of greenhouse gases associated with extraction of raw materials, processing, manufacture, transport and disposal. It is intended to work at a national level and as such, compromises must be made to simplify the data to a meaningful magnitude, for example using average transport distances.

Some life cycle stages have been excluded from the Carbon Metric method, where they vary widely depending on the use of the material, and where they do not substantially affect the results of the analysis. These choices are documented and explained in full in this report. As such, the Carbon Metric is not designed to provide a "carbon footprint" of any material or product but to estimate the difference between alternative waste management options. In its approach, it therefore varies from official life cycle assessment methodologies such as ISO 14040 and PAS 2050, but remains in the spirit of these and other standards.

Environmental Impact can be measured using a number of indicators, such as toxicity, acidification or climate change. The choice of indicators will depend on the exact nature of the application as well as time and resource constraints. The Carbon Metric relies on climate change as an indicator of environmental impact. This will allow the Zero Waste plan to align its priorities with other policy measures, such as the 2020 and 2050 Climate Change targets for Scotland, as set out in the 2009 Climate Change (Scotland) Act.

This report sets out the goal and scope of the Carbon Metric Methodology, including the boundaries of the data considered in the estimation of the environmental impacts of materials and products.

The data sources used in the methodology and the standards adopted to ensure the Carbon Metric was based on the highest quality data available. Although every effort has been made to ensure data meets these quality criteria, it has been necessary to relax these measures for materials and products where up to date and relevant research does not exist. These anomalies are documented in full in this report.

Finally, this report explains how the data on emissions from materials and products is converted into the Carbon Metric. Firstly, for every material and product considered in the Carbon Metric, the emissions for each end of life option are brought together in a single table of Carbon Factors. These Carbon Factors are then used to calculate Carbon Weightings, where each material or product is given a weighting based on its Carbon Factors and ranked according to the product with the highest environmental impact. These weightings are then used to calculate the Carbon Metric itself. In this way, the final Carbon Metric results allow materials and products with greater environmental impacts, to figure more significantly when strategic choices about waste are made.

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Contents

1.0 Introduction to the Carbon Metric ... 8

2.0 Purpose and Use of the Carbon Metric Methodology ... 9

3.0 Life Cycle Impacts ... 10
3.1 Life Cycle Assessment and Life Cycle Thinking ... 10
3.2 Why Use Climate Change as an Indicator for Environmental Impact? ... 11
3.3 Global Warming Potentials ... 13
3.4 Intended use of the Carbon Metric ... 13

4.0 The Scope of the Carbon Metric ... 15
4.1 System boundaries ... 15
4.2 Treatment of Biogenic Carbon ... 16
4.3 Extraction of Raw Materials and Manufacture of Products ... 16
4.4 Transport ... 16
4.5 End of Life ... 19
4.6 Reuse ... 20

5.0 Data Quality ... 21
5.1 Data Quality Standard ... 21
5.2 Data Sources ... 21
5.3 Use of data below the set quality standard ... 22

6.0 Calculating the Carbon Metric ... 24
6.1 Calculating the Carbon Factors ... 24
6.2 From Carbon Factors to Weightings ... 26
6.3 The Carbon Metric Calculation ... 28

7.0 The Carbon Trust Review ... 29

8.0 Conclusion ... 30
8.1 Summary ... 30
8.2 Recommendations for development of the Zero Waste Plan Carbon Metric ... 30

Annex 1 Energy from Waste ... 31
Annex 2 Approach to Recycling ... 32
Annex 3 Anaerobic Digestion ... 33
Annex 4 Data Sources ... 35
Annex 5 Material Substitution Rates for Recycling ... 38
Annex 6 Greenhouse Gas Conversion Factors ... 40

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Glossary

Biogenic Carbon – Carbon involved in the short loop of the global carbon cycle rather than the long or geological loop. Carbon from biogenic sources such as forests may be sustainably used if they are replenished at the same rate that they are destroyed.

Carbon Factors – figures for each material or product considered under the Carbon Metric, taken from a variety of data sources, which estimate the environmental impact of each life cycle option for the material or product. All carbon factors are given in the units Caron Dioxide Equivalents (CO_2eq).

Carbon Metric – The final figure for each material or product, based on the carbon weighting and tonnage. The Carbon Metric gives a figure, based on the environmental impact of each material or product, which allows comparisons and strategic decisions regarding waste issues to be made.

Carbon Weightings – The creation of unitless figures between 0 and 100 based on the Carbon Factors of each material or product relative and ranked according to the material with the highest environmental impact – clothing. The weightings can be used, along with the tonnage data, to find the Carbon Metric for each material or product. This is the final step in the creation of the Carbon Metric.

Capture rates – A measure of how much of the material available for recycling is actually disposed of via this route.

Closed loop recycling – This occurs when a material is substituted for the same primary material in a similar application.

Global Warming Potential – An index which measures the ability of a gas to absorb radiative heat in the atmosphere over a given period of time. The index is relative to the impact of carbon dioxide and measured in CO_2eq.

Guidance Report – The accompanying report to this technical document is entitled "The Scottish Carbon Metric for Recycling Performance – Guidance" and also known as the Guidance Report. The Guidance Report is intended to act as a non-technical summary of the Carbon Metric. It can be accessed, along with the Carbon Metric Calculator via the Scottish Government website.

ISO - The International Organization for Standardization is a network of national standards institutes which have created an international recognised system for approaching a variety of issues, including Life Cycle Analysis.

ISO 14040 - The ISO standard which describes the principles and framework for LCA including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.

ISO 14044 – The ISO standard which specifies requirements and provides guidelines for LCA including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.

Life Cycle Assessment (LCA) – A standardised process used to estimate the impact that a product or process has over the whole of its lifespan, including extraction of raw materials, construction, use and disposal.

Life Cycle Thinking – Adapting the theory underpinning full Life Cycle Assessment to products and processes for which there is not enough data for a full assessment.

Mid-point Indicators – An indicator which measures an effect midway through the process of creating an environmental impact. For example, CO_2eq emissions are a midpoint indicator because they measure the production of greenhouse gases, rather than the endpoint effect – climate change impact.

Open loop recycling – This occurs when a material is recycled into other product systems and the material undergoes a change to its inherent properties.

PAS 2050 – Publically Available Standard (PAS) developed as method for measuring embodied carbon from goods and services.

Recycling rates – A measure of the total amounts of a material which is disposed of by recycling.

SimaPro – Life Cycle Assessment software containing a range of databases.

WasteDataFlow – The web based system for municipal waste data reporting by UK local authorities to government.

WRATE – The Waste and Resource Assessment Tool for the Environment is a tool developed by the Environment Agency which compares the environmental impacts of different municipal waste management systems.

Zero Waste Plan – A plan developed by the Scottish Government and launched in June 2010 which sets out the Scottish Government's vision for a zero waste society.

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1.0 Introduction to the Carbon Metric

In June 2010 the Scottish Government published Scotland's Zero Waste Plan[1]. This sets the strategic direction for waste policy in Scotland, underpinned by a determination to achieve the best overall outcomes for Scotland's environment, by making best practical use of the priorities in the waste management hierarchy: waste prevention, reuse, recycling, recovery and landfill.

There are clear reasons to maintain the use of weight as a measure and target as it is universally understood and forms the basis for relevant European Union Directives. However, during the Zero Waste Plan consultation[2] exercise, a general view was expressed that using waste tonnage as a basis for measuring progress does not always promote waste prevention, reduction and re-use and does not focus recycling towards the waste material with the greatest environmental impact. In addition to this, Article 11(1) of the 2008 Waste Framework Directive[3] requires Member States to take measures that promote high quality recycling. There is therefore a need to look beyond weight to other indicators which can address these concerns.

The Scottish Government has developed a Carbon Metric which could address concerns regarding quality and environmental impact. Since publication of the Zero Waste Plan, the Scottish Government has established a stakeholder group with Zero Waste Scotland and the Chartered Institution of Waste Management (CIWM) the role of which was to critique and improve the proposed Carbon Metric. This report details the theory and methodology used to create this Carbon Metric and recommendations on how this could be developed in the future. The Carbon Trust has peer reviewed the methodology and data sources used to create the Carbon Metric. The conclusions of this review are detailed in Section 8.

Developing a Carbon Metric that truly reflects the environmental value or impact of waste management options is challenging, as many variables need to be considered. The use of any new Carbon Metric needs to be consistent with the Scottish Government's goal of valuing resource not waste, and prioritise the prevention, reuse and recycling of waste with the greatest environmental impact.

The Scottish Government intends to use the Carbon Metric alongside tonnage as a performance measure and target, and has set a target to achieve 70% recycling/composting and preparing for re-use of all waste by 2025, based on carbon. The objective of the Carbon Metric is to encourage greater levels of recycling of materials with the greatest environmental impact. In future publications of the Carbon Metric, it is hoped that there will be sufficient data to include the environmental impacts of other waste management options, such as prevention and reuse in the calculation of the carbon weightings.

The Scottish Government proposes to review the carbon data and analyses linked to the weightings reporting system described in this guidance document at appropriate intervals, to take account for updates in literature and available evidence. It will then make any necessary adjustments to the performance monitoring calculations where evidence suggests that this is necessary.

The Scottish Government intends to use the metric to assess recycling performance for Scotland, for all sources of waste (i.e. household, commerce, industry, construction and demolition). Sufficient data exists for Local Authority Collected Municipal Wastes (LACMW) to apply the metric in the near future, however further data on household waste composition is required in order for the Carbon Metric Reporting System to be used to assess performance against the household waste targets for 2013 and 2020. Further improvements in data collection for other waste sectors (a further action of the Zero Waste Plan) will then make it possible for the 2025 target for all wastes to be assessed in terms of Carbon Metric Performance.

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1 *Scottish Government (2010) Zero Waste Plan. Available at: http://www.scotland.gov.uk/Publications/2010/06/08092645/0*

2 *Scottish Government (2010) Zero Waste Pl.an Consultation. Available at: http://www.scotland.gov.uk/Publications/2009/08/19141153/0*

3 *EU Waste Framework Directive (2006). Available at: http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32006L0012:EN:NOT*

2.0 Purpose and Use of the Carbon Metric Methodology

The purpose of this document is to:

- Outline an agreed goal and scope;
- Outline agreed life cycle stages to be included (and excluded);
- Outline secondary data sources to be used, and;
- Recommend the Carbon Factors to be used and advise how these will be updated.

The Carbon Metric will allow comparisons and end of life decisions to be made for materials and products considered which takes into account the environmental impact of each choice. Materials which have a large carbon benefit of being recycled over sending to landfill will be given a greater significance though the Carbon Metric. This will increase the importance given to recycling these materials relative to other materials which are less carbon intensive to send to landfill.

The Carbon Metric is intended to be used to assess recycling performance for Scotland, for all sources of waste (i.e. household, commercial and industrial, construction and demolition). Currently, sufficient data only exists for Local Authority collected Municipal Waste and not all waste streams. SEPA will report Local Authority recycling performance both in terms of tonnage and carbon from the first quarter after publication of the final metric and the first Carbon target is in 2013. By 2025, the Carbon Metric will be applied to the 70% target for all wastes.

The Carbon Metric will not change how local authorities report their data. Data should still be reported through WasteDataFlow as weight (tonnage). The weighting system for carbon will be applied to that tonnage by SEPA and both recycling (tonnage and carbon) rates will be published.

This document lays out the methodology and evidence that has been used to develop the Carbon Metric. The Carbon Metric comprises a ranked list of weightings for materials and products based on the relative environmental impact of each item, measured in terms of their contribution to climate change. These weightings were created using Carbon Factors for relevant life cycle stages of each material or item based on the most up-to-date and relevant data available. This report is intended to document the creation of the Carbon Metric, through the assembly of Carbon Factors from referenced data sources and Life Cycle theory to create ranked Carbon Weightings for each material and product. Practical guidance on how to use the weightings derived from the carbon emissions figures described in this report is available separately in the accompanying "Scottish Carbon Metric for Recycling Performance – Guidance Report" here after known as the Guidance Report and accompanying Carbon Metric Calculator.

The assessment methodology is underpinned by the following standards:

- ISO 14040:2006: Environmental management — Life cycle assessment — Principles and framework
- ISO 14044:2006: Environmental management — Life cycle assessment — Requirements and guidelines
- PAS 2050 (2008): Specification for the assessment of the life cycle greenhouse gas emissions of goods and services
- The World Resource Institute and the World Business Council for Sustainable Development Greenhouse Gas Protocol Initiative[4]

It also draws on the work undertaken by Sevenster et al (2007)[5] in the Netherlands.

[4] *WRI (2005), Greenhouse gas Protocol Initative. Available at: www.ghgprotocol.org*

[5] *Sevenster, M., Wielders, L., Bergsma, G., Vroonhof, J., (2007)* Environmental indices for the Dutch packaging tax *Delft, The Netherlands, CE Delft*

3.0 Life Cycle Impacts

Section 3.1 introduces the concept of Life Cycle Assessment and Life Cycle Thinking and Section 3.2 explains how Life Cycle Thinking can be used to calculate environmental impact through the use of indicators and the choice of climate change as an indicator for the Carbon Metric. In Section 3.3, the practicalities of climate change as an indicator are discussed with particular reference to the use of Global Warming Potentials in the methodology. Finally, Section 3.4 examines the intended use of the Carbon Metric in Scotland.

3.1 Life Cycle Assessment and Life Cycle Thinking

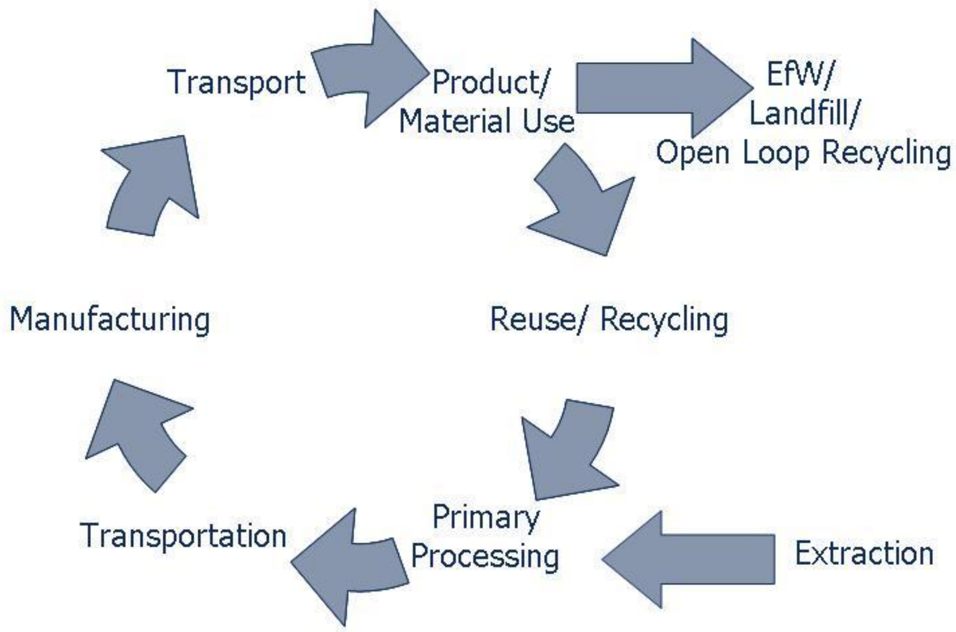
Life Cycle Assessment (LCA) is used to quantify the environmental impacts associated with a specific product, supply chain and waste management option. This allows comparisons to be made between materials, products and life cycle options depending on the different environmental impacts of each option.

Clearly, for a national indicator it is not feasible to consider the specific origin of all materials which become waste, or the details on the markets to which particular local authorities send their waste.

The approach proposed in this report builds on Life Cycle Thinking, rather than strict LCA. Life Cycle Thinking incorporates the basic approach of LCA without requiring a detailed assessment of each product or process. Whilst it is informed by standards on life cycle assessment, it does not use an approach which is compliant with such standards for the purposes of making environmental claims about specific products or packaging. Nonetheless, the methodology is considered appropriate for the purposes of taking measures which will lead to reductions in the environmental impact of waste management, and for estimating the magnitude of such changes. The Carbon Metric is therefore based on a number of assumptions about what happens, which are considered representative for Scotland.

Life Cycle Thinking is essential when considering environmental impacts associated with goods and services. By considering all stages in the life of a product, illustrated in Figure 3.1, from extraction of raw materials through to the end of its life, we can ensure that measures taken at one stage do not lead to unintended consequences in another, and highlight the actions with the greatest potential for improvement. Life Cycle Thinking is already implicit in the way government uses weight-based targets to move up the waste hierarchy, but will be made clearer still through the use of this Carbon Metric.

Figure 3.1 Simplified Life Cycle of a Product



Using a life cycle approach can also help to ensure that an improvement in one environmental indicator does not lead to an adverse impact in another category. This is dependent on the categories being considered.

Life Cycle Thinking can support a range of policy needs. Recent European research[6] has found that although our use of materials has been decoupling from economic growth in relative terms, in absolute terms they have remained constant for a decade. In absolute terms, this level of resource use is still unsustainably high, and many of the burdens associated with using these resources have been shifted abroad as the balance of trade itself has shifted. The consumption of these resources has a negative impact on the environment, be it via air emissions, emissions to water, solid waste, the extraction of raw materials and / or through the use of energy.

Examples of Life Cycle Thinking in European Union policies include the Integrated Product Policy Communication (COM (2003) 302)[7], as well as the two Thematic Strategies on the Sustainable Use of Natural Resources (COM (2005) 670)[8], and on the Prevention and Recycling of Waste (COM (2005) 666)[9]. The Sustainable Consumption and Production Action Plan (SCP)[10] integrates these and other related policies, aiming to reduce the overall environmental impact and consumption of resources associated with the complete life cycles of goods and services (products).

The use of weight-based and carbon-based targets in a complementary fashion can facilitate the delivery of a range of policy, strategy and operational outcomes, and can lead to more informed decision-making. Through the use of methodologies for Life Cycle Assessment and Carbon Footprinting, the relationship between materials and emissions may be reviewed in tandem by Local Authorities to optimise their waste prevention and management operations.

3.2 Why Use Climate Change as an Indicator for Environmental Impact?

3.2.1 Environmental Impact Indicators

All products and materials have a range of environmental impacts. For each item, different environmental impacts may be viewed as more significant or less significant by society.

In Life Cycle Assessment, indicators are used to measure changes in a system as the result of environmental impacts. A commonly used set of environmental indicators have been developed by the Centre of Environmental Science (CML) at Leiden University, the Netherlands. These indicators cover resource depletion, climate change, acidification potential and many others, Box 3.1 provides some examples.

Box 3.1 Mid-point Indicators of Environmental Impact from the Centre of Environmental Science, Leiden University

Depletion of abiotic resources
This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation.

Climate change
The characterisation model for climate change, as developed by the Intergovernmental Panel on Climate Change (IPCC), is selected for development of characterisation factors. Factors are expressed as Global Warming Potential (GWP) for a time horizon of 100 years (GWP100), in kg carbon dioxide equivalent/kg emission.

Toxicity indicators addressing human toxicity and aquatic eco-toxicity
Characterisation factors, expressed as Toxicity Potentials, are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance the toxicity potentials are expressed as 1,4-dichlorobenzene equivalents/ kg emission.

Acidification
Acidification has direct and indirect damaging effects, such as nutrients being washed out of soils, increased solubility of metals into soils, and damage to stone buildings. But even buildings and building materials can be damaged. Acidification Potentials (AP) is expressed as kg SO_2 equivalents/ kg emission.

Several other indicators may be used covering other environmental issues. In addition, much of the data input to derive these factors may be of direct interest, such as Cumulative Energy Demand and operational or embedded water use.

No single indicator can holistically cover environmental impact, and for different materials, different environmental factors will be the dominant concern. For example, nuclear energy produces few greenhouse gas emissions and does not produce gases which lead to acidification or much solid waste. It is the nature of the resultant waste materials - and the concerns over the effects of radiation - which are considered more important indicators of environmental impact by society in this context.

The consideration of more environmental issues would lead to more informed decision making. However, it would also require collation and interpretation of more data. In practice this would make the targets complicated to understand and monitor, and costly for Government to administer. As such, it is more usual to consider a few or even a single indicator as a basis for an environmental metric. It is therefore, important to ensure that the choice of indicator reflects the key environmental impacts considered by the Carbon Metric and its audience.

3.2.2 Climate Change as an Indicator

The Carbon Metric uses climate change as its indicator for environmental impact. There are a number of reasons for considering climate change as a proxy for a wider range of environmental issues.

The Scottish Government has set a target through the Climate Change Act (Scotland) 2009 to ensure that the net Scottish carbon account for the year 2050 is at least 80% lower than 1990 levels with an interim target to reduce greenhouse gas emissions by 42% by 2020[11]. Consequently, there is a need to both reduce the amount of resources we consume, and reduce the emissions associated with consuming these resources. This has recently been acknowledged in the Scottish Governments draft Report on Proposals and Policies for a Low Carbon Scotland, which identifies "treating resources as high up the waste hierarchy as possible by preventing, reusing or recycling" as a priority of the Zero Waste Plan[12].

Reducing resource consumption through waste prevention, re-use and recycling will reduce the environmental impacts from the extraction of primary raw materials and from the transformation of primary raw materials in production processes as well as reducing waste to landfill. Waste management represents more than the end of a products life; it is an integral part of resource management.

In addition to the concerns of respondents to the Zero Waste Plan consultation, the proposal for action based on greenhouse gas emissions addresses a number of drivers. The Stern Review[13] concludes that climate change is "the greatest and widest-ranging market failure ever seen." To correct this failure, and to allow Scotland to meet the targets set in the Climate Change Act, we need not only to review the resources we use to provide our goods, but also to use these more effectively. In this sense, weight may be seen as a useful indicator, showing the tonnes of material used to deliver a desired output. However, on its own, weight does not provide an indication of other environmental impacts associated with goods we use.

Scottish Government targets relating to climate change focus on emissions which originate within Scotland or allocated to member state in terms of EU Emissions Trading System. This is the approach commonly adopted by the international community. However, the international nature of the market for key raw materials and recyclables means that many of the savings from waste management would not alter the Scottish territorial account.

For example, the majority of primary aluminium used in the UK is sourced from South America, whilst recycling occurs in the UK and Europe. From a global perspective, every tonne of aluminium recycled avoids 9 tonnes CO_2eq emissions. However, all avoided emissions will occur outside of Scotland, and so the savings do not contribute to targets under the Scottish Climate Change Act. In addition, every tonne of High-density polyethylene (HDPE) plastic recycled avoids approximately 1 tonne CO_2eq emissions, but if the plastics are exported for recycling, again the benefit does not accrue to national carbon accounts.

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[11] *The Scottish Government (2009), the Climate Change (Scotland) Act. Available at: http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact*

[12] *The Scottish Government (2010), Low Carbon Scotland: A Draft Report on Proposals and Policies. Available at: http://www.scotland.gov.uk/Resource/Doc/331949/0107999.pdf*

[13] *Stern, N. (2006)* The Economics of Climate Change*, London: HM Treasury. Available at: http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/stern_review_report.htm*

Certain aspects are relevant to territorial carbon accounts. For example, changes in landfill gas emissions and in emissions from domestic energy from waste would contribute to emissions under the Climate Change Act. However, in general, the two measures, whilst complimentary, are not compatible. This is because the trade in goods and recyclate are international, and many of the impacts of manufacture, and the benefits of recycling, occur outside of Scotland. By contrast, the Climate Change Act is concerned only with emissions which arise within Scotland (e.g. landfill emissions). This should be recognised in using the outcome of this Carbon Metric.

In addition to this, the use of a Carbon Metric based on Climate Change impacts can complement a range of other targets and initiatives, such as the EU Landfill Directive targets on biodegradable municipal waste, recycling targets, reductions in packaging weight and the Integrated Product Policy Directive.

3.3 Global Warming Potentials

Using climate change as an indicator of environmental impact requires that the amount of greenhouse gases produced in relation to a material or product are estimated. Whilst carbon dioxide is a commonly produced greenhouse gas in many processes, it is not the only contributor to climate change.

To allow comparison between the impacts of different greenhouse gases the Intergovernmental Panel on Climate Change (IPCC) has created an internationally recognised index of Global Warming Potentials (GWP). The GWP is based on the potential for each gas to absorb heat (also known as its radiative force) and the length of time it is present in the atmosphere. The index is relative to carbon dioxide, which is given a GWP value of 1 for a given time horizon, commonly 100 years. The GWP for other gases are then calculated and given a value which represents the environmental impact of one molecule of the gas relative to carbon dioxide. For example, methane has a GWP of 25, which means one molecule of methane has 25 times the environmental impact of one molecule of carbon dioxide over a 100 year period.

GWP have been used to measure the environmental impact of greenhouse gases created in the Life Cycle of each material and product considered in the Carbon Metric.

Key GWPs used in the methodology of the Carbon Metric are reproduced in Annex 6. For a calculation of lifetimes and a full list of greenhouse gases and their GWP please refer to Solomon *et al.*, (2007). General data sources are covered in Section 5.2. Where primary data is available, GWPs, in CO_2eq, are the latest available from the IPCC Fourth Assessment Report[14]. Other conversion factors are taken from the IPCC Emissions Factor Database[15].

Most figures are taken from published reports, in which the GWP of different gases has already been converted to CO_2eq. In these cases, it has not been possible to check or update the conversion factors used. These may not therefore be the latest available GWPs, which are regularly updated by the IPCC as new research refines the estimates. However, whilst it is important to note this inconsistency, it is unlikely that this will significantly influence the results, as most changes are relatively small.

3.4 Intended use of the Carbon Metric

The Scottish Government intend to apply the Carbon Metric to all wastes with respect to the 2025 recycling targets, as detailed in the Zero Waste Plan. In order to calculate the Carbon Metric detailed waste management data is required. This is recognised by the SG and the ZWP also describes a range of improvement to waste data that will be needed in the coming years.

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14 *Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) (2007)* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change *Cambridge University Press, Cambridge, United Kingdom Table 2.14.* Lifetimes, radiative efficiencies and direct (except for CH_4) global warming potentials (GWP) relative to CO_2. *Available at:* *http://www.ipcc.ch/ipccreports/assessments-reports.htm*

15 *IPCC (2006) Guidelines for National Greenhouse Gas Inventories. Emissions Factor Database. Available at:* *http://www.ipcc-nggip.iges.or.jp/EFDB/main.php*

Currently the most developed waste data is available for local authority-collected municipal waste reported through WasteDataFlow, therefore in the first instance the methodology and range of materials investigated in this document cover the materials that are most relevant to this waste stream. The principles of the Carbon Metric apply equally to commercial and industrial and construction and demolition waste.

4.0 The Scope of the Carbon Metric

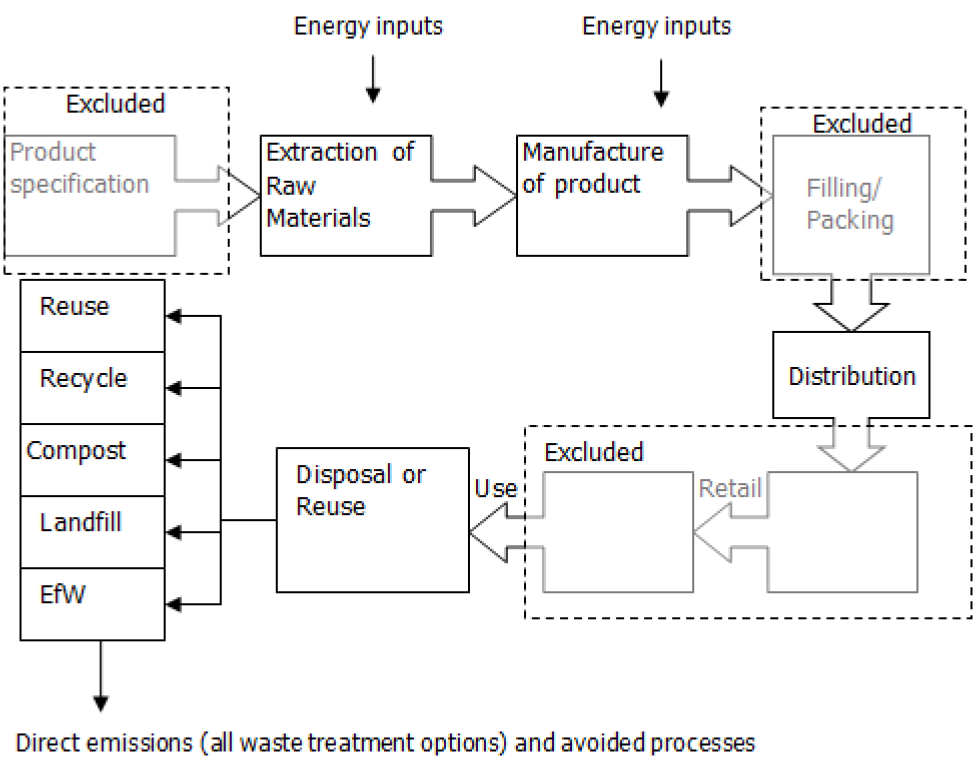
The materials and products covered by this Carbon Metric were specified by the Scottish Government, based on an understanding of the composition of waste and data which would be reported by Local Authorities under WasteDataFlow. It is not designed to be an exhaustive list, but should address the majority of waste streams. The range of materials covered by the weightings may need to be extended as commercial and industrial waste streams are brought into the Carbon Metric.

Section 4.1 details the system boundaries applied to the data sources. Section 4.2 explains how biogenic carbon, an issue which can be covered in more than one way in LCA, is considered in the Carbon Metric methodology. Section 4.3 – 4.6 explore how specific stages of the Life Cycle of materials and products are considered in the Carbon Metric methodology.

4.1 System boundaries

The flow chart below shows the steps that would typically be included in a full product LCA. It is proposed that the following steps are included / excluded from the carbon calculation for the purposes of the Zero Waste Plan. The reasons for excluding each section highlighted in the flow chart are explained below.

Figure 4.1 Life Cycle Stages included and excluded from the Carbon Metric



Product specification is the most influential stage in the life cycle of the goods we buy, since it determines many of the carbon intensive features of the product (e.g. material, weight, and cost). However, this stage is not assumed to contribute significant direct emissions. Therefore, it has been excluded from the Carbon Metric methodology.

The stages associated with filling and packing a product, have been also been excluded. This is because the impact of this stage is specific to the product. Although this may be an important source of emissions with regard to waste prevention activity, it does not materially affect the difference between other stages of the waste hierarchy (recycling, energy recovery, and landfill) because forming, filling and packing will be the same whatever the disposal method. Since these factors will be utilised at a national level, it is recommended that this stage is excluded from the factors.

4.2 Treatment of Biogenic Carbon

When considering the impacts of extraction and disposal of materials in carbon-based terms, there is a need to distinguish between the carbon dioxide which arises from fossil fuels (so-called "long cycle" carbon or "fossil CO_2") and that which is taken up by plants and released when the plant degrades ("short cycle" carbon or biogenic CO_2).

By extracting and burning fossil fuels, fossil carbon is being moved from one store (underground) to another (the atmosphere). This creates an imbalance and leads to an increase in atmospheric carbon. In contrast, the biogenic carbon can be said to be in a short cycle, as carbon is taken up from the atmosphere, whilst flora and fauna are alive, and released at the end of their life (i.e. inputs equal outputs). This has the effect that, in a sustainable production system, over the whole life of the material the carbon account can be considered neutral. The burning of fossil fuels releases stored carbon into the atmosphere and cannot be considered neutral.

Where a production system is unsustainable (e.g. clear-felling of forests), biogenic CO_2 uptake and emissions may not be balanced, and use of renewable materials may cause CO_2 to be emitted to the atmosphere.

In this methodology, it is proposed that biogenic CO_2 is excluded from the calculations, and that it is assumed that biomass is derived from sustainable sources. Other biogenic greenhouse gases (methane and nitrous oxide) will be accounted for. As an illustration, this would mean that CO_2 absorbed by trees as they grow is not counted, but when paper is disposed of by landfill or energy recovery, CO_2 emissions are not counted either. The alternative would be to give paper and card products a carbon credit during production, and then showing this emission at end of life. Emissions from energy recovery would appear counterintuitive to many, as more CO_2 would be released per kWh electricity generated from paper than energy generated from fossil fuels.

4.3 Extraction of Raw Materials and Manufacture of Products

Information on the extraction of raw materials and manufacturing impacts are commonly sourced from the same reports, typically life cycle inventories published by trade associations. The sources utilised in this study are listed in Annex 4. The stages covered include mining activities for non-renewable resources, agriculture and forestry for renewable materials, production of materials used to make the primary material (e.g. soda ash used in glass production) and primary production activities such as casting metals and producing board. Intermediate transport stages are also included. Full details are available in the referenced reports.

Carbon Metrics have been provided for a combination of materials (e.g. paper) and products (e.g. shoes). Where information is provided on a product, the carbon factor provided accounts for secondary manufacturing activity (e.g. the manufacture of a shoe from raw materials). Where data is provided for a material, this typically excludes the forming of a product from this raw material. As discussed in Section 4.2, the reason for excluding this stage is that the impacts can be very different depending upon the product being made. Without a compositional analysis of what the products are, it is considered inappropriate to include forming emissions. The consequence of this decision is that the figures presented for waste prevention are an underestimate of the true impact of waste prevention activities. The exclusion does not affect the relative difference between other waste management options.

4.4 Transport

Once materials have been manufactured, they are transported to factories where they are used to make a variety of goods. The following transportation distances and vehicle types have been assumed for this methodology. The impact of transporting the raw material (e.g. forestry products, granules, glass raw materials) is already included in the manufacturing profile for all products:

Table 4.1 Distances and transportation types used in the calculation of the Carbon Metric

Destination / Intermediate Destination	One Way Distance	Mode of transport	Source
Transport of raw materials to factory	112km	Average, all HGVs	Department for Transport (2009)[16] Based on average haulage distance for all commodities, not specific to the materials in the first column.
Distribution to Retail Distribution Centre & to retailer	95km	Average, all HGVs	McKinnon (2007)[17] IGD (2008)[18]

Transport emissions from distribution from the manufacturer to the retailer could be excluded from the analysis for the same reasons given above for excluding forming. However, these emissions have been included in preparation for further development of the Carbon Metric to include other waste management options. These distribution emissions do not make a significant difference to the carbon factors.

Transport of goods by consumers is excluded from the scope of the Carbon Metric. Again, although this may be an important source of emissions with regard to waste prevention activity, but it does not materially affect the difference between other stages of the waste hierarchy (recycling, energy recovery and landfill). Since these factors will be utilised at a national level, it is recommended that this stage is excluded from the life cycle calculations.

The Department of the Environment, Food and Rural Affairs (DEFRA)[19] and Greenhouse Gas Protocol[20] guidelines on vehicle emissions have been used for most vehicle emission factors. The 2010 DEFRA update provides emissions factors for the non-CO_2 greenhouse gases methane and nitrous oxide as well, based upon the emission factors used in UK Greenhouse Gas Inventory (GHGI). These have been amended to ensure consistency with the IPCC Fourth Assessment Report. However, please note that this makes a difference of less than 1 gram CO_2eq per tonne to the published figures. The DEFRA guidelines exclude emissions associated with the production and transportation of the fuel are excluded from these figures. In discussion with the Carbon Trust, we have included a factor to account for these emissions.

16 *Department for Transport (2009)* Transport Statistics Bulletin: Road Freight Statistics 2008 *National Statistics Table 1.14d. Available at:* http://www.dft.gov.uk/pgr/statistics/datatablespublications/freight/goodsbyroad/roadfreightstatistics2008

17 *McKinnon, A.C. (2007)* Synchronised Auditing of Truck Utilisation and Energy Efficiency: A Review of the British Government's Transport KPI Programme. *Available at:* http://www.sml.hw.ac.uk/logistics/downloads/efficiency/Review%20of%20Transport%20KPI%20programme%20(WCTR%202007).pdf

18 *IGD (2008) UK Food & Grocery Retail Logistics Overview Date Published: 15/01/2008. Available at:* http://www.igd.com/index.asp?id=1&fid=1&sid=17&tid=0&folid=0&cid=223

19 *The Department of Rural Affairs (DEFRA) (2010). Greenhouse Gas Conversion Factors. Available at:* www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

20 *The Greenhouse Gas Protocol (2010). Available at:* www.ghgprotocol.org/downloads/calcs/co2-mobile.pdf

Figures for Refuse Collection Vehicles have been taken from the Environment Agency's Waste and Resource Assessment Tool for the Environment (WRATE)[21].

Transport distances for waste were estimated using a range of sources, principally data supplied by the Environment Agency for use in the WRATE tool (2005). The distances adopted are shown below.

Table 4.2 Distances used in calculation of the Carbon Metric

Destination / Intermediate Destination	One Way Distance	Mode of transport	Source
Household, commercial and industrial landfill	25km by Road	26 Tonne Refuse Collection Vehicle, maximum capacity 12 tonnes	WRATE (2005)
Inert landfill	10km by Road		WRATE (2005)
Transfer station / CA site	10km by Road		
MRF	25km by Road		
MSW incinerator	50km by Road		
Cement kiln	50km by Road		
Paper and Card	41% 250km by Road, 59% 250km by road, 18000km by Boat to Guangdong, 50km by road	Average, all HGVs	WRAP (2008)[22]
Glass (Container – Clear and Amber)	50km by Road		WRATE (2005)
Glass (Container Green) 24% total	50km by road and 390km by Boat		WRAP
Glass – construction aggregate	50km by Road		WRATE (2005)
Aluminium	50% 250km by Road, 50% 50km by road and 390km by Boat	Average, all HGVs, 5000-10,000 TEU capacity vessel. For China, the vehicle is assumed to be 32 tonne vehicle meeting Euro II emissions criteria	WRAP estimate based on Hull – Rotterdam
Steel/Iron	34% 250km by Road, 66% 50km by road and 390km by Boat		
Plastics	33% 250km by Road, 67% 250km by road, mixed plastics 17600km by Boat to Hong Kong, PET 19000km by Boat to Shanghai, HDPE 18000km by Boat to Tianjin, then 150km by road (80km for mixed plastic)		WRAP (2008)
Wood	50km by Road	Average, all HGVs	WRATE (2005)
Inert recycling	10km by Road		WRATE (2005)

Road vehicles are volume limited rather than weight limited. For all HGVs, an average loading factor (including return journeys) of 56% is used based on DEFRA (2009)[23]. Waste vehicles leave a depot empty and return fully laden. A 50% loading assumption reflects the change in load over a collection round which could be expected.

For international sea freight, there is a trade imbalance between Europe and the Far East. This means that vessels may return empty (but with ballast), or partially empty, unless they were carrying materials for recycling. In these

21 *Environment Agency (2010), Waste and Resource Assessment Tool for the Environment. Available at:* *www.environment-agency.gov.uk/research/commercial/102922.aspx*

22 *The Waste and Resource Action Programme (WRAP) (2008)* CO_2 impacts of transporting the UK's recovered paper and plastic bottles to China*; Banbury. Available at:* *http://www.wrap.org.uk/downloads/CO2_Impact_of_Export_Report_v8_1Aug08.67624114.5760.pdf*

23 *DEFRA (2009). Greenhouse Gas Conversion Factors. Available at:* *http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm*

circumstances, it would be appropriate to consider only the marginal emissions, i.e. those incurred by moving the additional weight of the freight, but not of the vessel itself.

4.5 End of Life

In landfill, it is assumed that as biogenic materials degrade, they will release greenhouse gases, including methane. A proportion of this is captured for flaring or electricity generation. In this methodology, we assume that 75% of methane is captured, of which 46% is used for electricity generation, at a generation efficiency of 35%[24]. 10% of uncaptured methane is assumed to be oxidised at the cap. These figures are also liable to change over time.

Emissions from the landfill of different materials are calculated using WRATE and the LandGem model[25]. Methane generation rate constants have been taken from IPCC[26].

For energy recovery, a typical efficiency for energy production of 23% has been assumed. Detail on this assumption is provided on Annex 1.

When considering recycling, for some materials there are limited options, whereas for others there is significant choice in how to use materials. For example, recycled metal invariably replaces primary metal, whereas recycled glass may be used in place of glass or aggregates, and plastic may be used in place of wood or textiles. Recycling may take place in the UK or abroad, and the proportion recycled domestically varies widely between materials. In this document, only two options have been considered: closed and open loop recycling.

The definition of closed and open loop recycling used is discussed in Annex 2, but closed loop occurs when the recycled material substitutes the same primary material in a similar quality application.

Where an item enters open loop recycling, the impact of processing the recyclate has been included in the carbon metric, but the avoided impact has been excluded. The reason for excluding the avoided impacts is consistency. For some materials, the avoided materials from open loop recycling are known and predictable. For others, the material is not known. In general the closed loop, rather than open loop, recycling figure is used with the methodology and this does not have a material effect on the results. However, it is an area for future improvement and is discussed in Section 8.2.

When an item is sent for recycling, it is rare for 1 tonne of collected material to displace 1 tonne of primary material due to losses in the recycling process. The quantity of material displaced by 1 tonne of recyclate is contained in Annex 5. These loss rates have been factored in when considering the benefit of collecting a tonne of material for recycling.

The data for local-authority collected municipal waste does not currently distinguish between recyclate that goes to open or closed loop recycling. For many materials closed loop recycling is the only option and for most materials it is closed loop recycling that is assumed in the weightings. The only materials that differ from this are:

- Glass, where sorted, glass is assumed to go to closed loop recycling but where the glass is collected as mixed colours, a proportion is assumed to be sent for remelt and a proportion is sent for use as aggregate replacement, based on data from Valpak;
- Food and garden waste, where closed loop recycling is not possible. Two different weightings are given for each, depending on whether the material is sent for composting or anaerobic digestion.

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[24] *Jackson J, Choudrie S, Thistlethwaite G, Passant N, Murrells T, Watterson J, Mobbs D, Cardenas L, Thomson A, Leech A (2009) UK Greenhouse Gas Inventory, 1990 to 2007: Annual Report for submission under the Framework Convention on Climate Change Annex 3. Available at: http://www.naei.org.uk/reports.php?list=GHG*

[25] *US EPA (2005) Landfill Gas Emissions Model (LandGEM) V3.02. Available at: http://www.epa.gov/ttncatc1/products.html*

[26] *IPCC (2006) Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan 2006. Available at: http://www.ipcc-nggip.iges.or.jp/*

The carbon-emissions associated with open loop recycling for additional figures are quantified in the methodology to allow for future extension of the Carbon Metric to take account of different recycling methods should sufficient waste data become available.

4.6 Reuse

At present, information on the impact of reuse is limited. Data is available on textiles and wooden pallets, but not for many common items (e.g. furniture). The current Carbon Metric incorporates reuse for clothing and shoes as this is the primary destination for the material that is currently recorded as recycled, and some data is available on the impacts associated with this. Future improvements in reuse data available may allow reuse to be accounted for differently in the Carbon Metric in the future as part of the review process.

5.0 Data Quality

This section explains the methodology for the choice of data used in the calculation of carbon emissions used in the Carbon Metric equations explained in Section 6. Section 5.1 details the indicators used to assess whether data met the data quality standards required for this project. Section 5.2 states the sources used to collect data. Finally, Section 5.3 explains and justifies the use of data which did not meet the data quality requirements.

5.1 Data Quality Standard

Data used in this methodology should meet the data quality indicators described in Table 5.1 below.

Table 5.1 Data Quality Indications for the Carbon Metric

Data Quality Indicator	Requirement	Comments
Time-related coverage	Data less than 5 years old	Ideally data should represent the year of study. However, the secondary data in material eco-profiles is only periodically updated.
Geographical coverage	Data should be representative of the products placed on the market in the Scotland / UK	Many datasets reflect European average production.
Technology coverage	Average technology	A range of information is available, covering best in class, average and pending technology. Average is considered the most appropriate but may not reflect individual supply chain organisations.
Precision / variance	No requirement	Many datasets used provide average data with no information on the range. It is therefore not possible to identify the variance.
Completeness	All datasets must be reviewed to ensure they cover inputs and outputs pertaining to the life cycle stage	
Representative-ness	The data should represent UK conditions	This is determined by reference to the above data quality indicators
Consistency	The methodology has been applied consistently.	
Reproducibility	An independent practitioner should be able to follow the method and arrive at the same results.	
Sources of data	Data will be derived from credible sources and databases	Where possible data in public domain will be used. All data sources referenced
Uncertainty of the information		Many data sources come from single sources. Uncertainty will arise from assumptions made and the setting of the system boundaries.

5.2 Data Sources

The methodology is based on published greenhouse gas emission data rather than data collected from onsite measurements directly.

Data has been taken from a combination of trade associations, who provide average information at a UK or European level, data from the Ecoinvent database and reports / data from third parties (e.g. academic journals, Intergovernmental Panel on Climate Change). Data on wood and many products are taken from published life cycle assessments as no trade association eco-profile is available. Data sources for transport are referenced in Section 4.4.

Data on waste management options has been modelled using SimaPro[27] and WRATE. Assumptions are identified in Annexes 1, 2 and 5, and Section 5.3. Scotland specific data was available for compost markets and has been used. For all other materials, UK or EU specific data has been used where possible.

The emissions data and weightings will be updated on a five year basis to take into account any new or improved information available, such as updates from the Scottish Environmental Protection Agency's (SEPA) Waste Data Strategy[28].

Some data sources used do not meet the quality criteria. The implications of this are discussed in the following section.

5.3 Use of data below the set quality standard

Every effort has been made to obtain relevant and complete data for this project. For the majority of materials and products data which fits the quality standards defined in Section 5.1 above are met. However, it has not always been possible to find data which meets these standards in a field which is still striving to meet the increasing data demands set by science and government. This section details data which do not meet the expected quality standard set out in the methodology of this project but were never-the-less included because they represent the best current figures available. The justification for inclusion of each dataset is explained. The most common data quality issues encountered concerned data age and availability. No Scotland-specific data on environmental impacts was identified.

5.3.1 Glass data

The most relevant data on glass is older than desired, being sourced from Enviros (2003)[29]. However, as the data is sourced from the UK, it is applicable to the Scotland and this project. The European Container Glass Federation (FEVE) has published a Life Cycle Inventory for glass at a European level[30]. This incorporates average European recycled content, rather than providing figures for 100% primary and recycled glass, and so cannot be used for the purposes of the Carbon Metric at present.

5.3.2 Wood and Paper data

Published data on wood products is sparse, an issue highlighted by the Waste and Resources Action Programme (WRAP) in 2006 and 2010[31]. Data used in this report for waste prevention is based on studies from the USA, where production processes may not be representative of activity in the UK (e.g. different fuel mix to generate electricity). This data should therefore be viewed with caution. Data on different types of wood has been used in combination with information on the composition of wood waste in the UK[32] to provide a figure which represents a best estimate of the impact of a typical tonne of wood waste.

Many trade associations publish data on the impact of manufacturing 100% primary and 100% recycled materials. However, for various reasons, the bodies representing paper and steel only produce industry average profile data, based on a particular recycling rate.

Furthermore, paper recycling in particular is dependent on Asian export markets, for which information on environmental impacts of recycling or primary production is rare. This means that the relative impact of producing paper from virgin and recycled materials is difficult to identify. The figure for waste prevention for paper represents average production, rather than 100% primary material, so already accounts for the impact of recycling. Caution should therefore be taken in using these numbers. There is a commitment by the Chinese Life Cycle Assessment

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27 *SimaPro (2010). Life Cycle Assessment Software. Available at: http://www.pre.nl/simapro/*

28 *SEPA 2010 Waste Data Flow Reports. Available at: http://www.wastedataflow.org/*

29 *Enviros (2003)* Glass Recycling - Life Cycle Carbon dioxide Emissions*; British Glass, Sheffield*

30 *PE International (2009) Life Cycle Assessment of Container Glass in Europe FEVE; Brussels*

31 *WRAP (2006) Environmental Benefits of Recycling and WRAP (2010) Environmental Benefits of Recycling – 2010 update. WRAP; Banbury. Available at: http://www.wrap.org.uk/downloads/Executive_summary_Environmental_benefits_of_recycling_-_2010_update.081ff1a9.8671.pdf*

32 *WRAP (2009) Wood Waste Market in the UK WRAP; Banbury. Available at: http://www.wrap.org.uk/recycling_industry/publications/wood_waste_market.html*

community to place more information in the public domain[33], but there is no timetable for this. As more information becomes available the Carbon Metric can be updated.

5.3.3 Steel data

The figures on steel production are an estimate only and should be treated as such.

5.3.4 Waste Electrical and Electronic Equipment

Information on Waste Electrical and Electronic Equipment (WEEE) is sourced from Huisman (2008)[34], a study for the United Nations University, which presents data on the benefit of recycling WEEE, but not total impacts. Although the figures contained are of good quality, they do not match the format of the other figures used in this report. As a consequence the carbon factors for WEEE include the benefit from avoided emissions which could not be disaggregated from the data source.

5.3.5 Plastics data

Whilst not an issue from a data quality perspective, Plastics Europe are in the process of updating the Life Cycle Inventories for plastic polymers. Again, as the publications are updated the factors for waste prevention for plastics can be updated.

Data on polystyrene recycling does not meet the age criteria, as it originates from one 2002 study. This will be updated as new sources are identified.

5.3.6 Textiles and footwear

The BIO IS study is the most relevant data source to calculate the carbon factors for textiles even though the report is not yet published. This is because the factor proposed is based upon the market share of all textile products in Europe, categorised by product types and fibre types. The factor is considered to be representative of household textiles in general rather than specific fibres. It is understood that this will be published by the EU.

Information for footwear comes from one study from the USA. As with wood, this may not reflect Scottish impacts, and so the results should be viewed with caution.

5.3.7 Non-automotive batteries data

Published information on non-automotive batteries addresses the relative impact of alternative waste management options, but not the impact of battery manufacture. Therefore, whilst recycling, energy recovery and landfill factors are available; there is no figure for waste prevention at present.

5.3.8 Oil Data

Vegetable oil factors are based on studies of rapeseed oil. There is discussion in scientific journals on which is the appropriate oil to use when assessing environmental impacts, since growth is strongest in palm oil manufacture and use. However, palm oil has particular properties (e.g. high ignition point) which mean its use as a standalone product, rather than as an ingredient in other products, is limited.

Mineral oil will be included in the Carbon Metric. Although there is no available data on waste arising for mineral oil, this waste stream is banned from landfill. Therefore, it is assumed that all collected mineral oil is recycled and the data on recycled mineral oil is used both for the arising and the recycled figure.

5.3.9 Excluded Materials and Products

For some materials and products, such as automotive batteries and fluorescent tubes, no suitable figures have been identified to date. Zero Waste Scotland is in the process of identifying factors for furniture and paint, but at present there are no plans to carry out primary research to obtain figures for the other waste streams.

[33] Second Chinese Conference on Life Cycle Management (CLCM2009), Nov.15-16, 2009 in Beijing. Available at: http://www.iscp.org.cn/conference/clcm2009en/program.html

[34] *Huisman, J., et al (2008)* 2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment – *Study No. 07010401/2006/442493/ETU/G4, United Nations University, Bonn Germany*

6.0 Calculating the Carbon Metric

This section of the report brings together the Life Cycle Thinking theory and the data on emissions of materials and products to explain how the Carbon Metric has been calculated, through a multiple step process described in Sections 6.1, 6.2 and 6.3 below.

Once collected, the data was used to create Carbon Factors relating to the impact of reducing, reusing, recycling or disposing of each material or product (Section 6.1). These Carbon Factors were then translated into Carbon Weightings, allowing materials and products to be given a ranked figure representing their environmental impact compared to other materials and products in the Carbon Metric. The Carbon Weightings could then be incorporated into the calculations of the Carbon Metric to find the total carbon incorporated in the waste stream (Section 6.3).

The Carbon Metric is intended to be used at a national level. As such, it is inappropriate to quote carbon data to the nearest kilogram. Therefore, it is proposed that all figures are rounded for reporting purposes to three significant figures. This approach may mean benefits of incremental improvements are not recognised, but changes and trends which occur at a national level will be clearly observed.

6.1 Calculating the Carbon Factors

6.1.1 From data to factors

The data was brought together in a single table, Table 6.2 below, where the environmental impact of each material and product was recorded in the same format using CO_2eq units. The Carbon Factors for all possible life cycle stage for each material and product where recorded. All Carbon Factors include associated domestic transport hence inert materials sent to landfill have some emissions associated with this option.

The resulting table allows users to calculate the impact of a particular Life Cycle option for a material or product and compare the impacts of different Life Cycle choices.

6.1.2 Example with Aluminium

An example of how the table can be used to calculate the Carbon Factors for aluminium is provided in Table 6.1 below.

For waste prevention, the Carbon Factor presented covers emissions associated with manufacturing a product. This figure could be used to show the benefit of reducing use of the specified material or product. In most cases it is not appropriate to use this figure for the benefit of reusing an item, as reusing one item may not avoid one new item. Zero Waste Scotland is carrying out further investigations into the benefits of reuse and will be providing updated figures for this in due course.

The environmental impact of one waste management option compared to another is calculated by finding the difference between the relevant columns. For example, the benefit of recycling aluminium is the difference between emissions from manufacturing (i.e. the waste prevention column), closed loop recycling emissions, and emissions from the avoided waste management option, in this example landfill.

The appropriate calculation in this instance is:

594 – 9821 – 21 = -9248 kg CO_2eq/tonne of aluminium

natural scotland
SCOTTISH GOVERNMENT

Table 6.1 Example of Carbon Factors for different Waste Management options for Aluminium cans and foil

Waste Management Option	**Carbon Factor for Aluminium (kg CO_2eq)**
Waste Prevention (avoidance excluding disposal)	9,821
(Preparation for) reuse	N/A
Open Loop Recycling (excluding avoided impacts)	N/A
Closed Loop Recycling	594
Energy Recovery (combustion)	31
Energy Recovery (Anaerobic Digestion)	N/A
Composting	N/A
Landfill	21

Comparing Waste Management Options

Recycling V landfill	594 – 9,821 – 21 = -9248
Recycling V Recovery	594 – 9,821 – 31 = -9258

Data Quality Requirements

Data Quality	
Representative	

Key:
Green – data meets all the quality requirements of the Carbon Metric
Yellow – data meets most of the quality requirements of the Carbon Metric
Red – data does not meet the quality requirements identified for the Carbon Metric. No alternative data identified.

The Data Quality column gives an estimate of the reliability of the data. The Representative column gives an estimate of the suitability of the data to be used in the Carbon Metric.

The material data was sourced from the European Aluminium Association (2008) Environmental Profile Report for the European Aluminium Industry[35]. Transport data was taken from the DEFRA/DECC Emissions Guidelines[36] and the Ecoinvent database[37], packaging data from CE Delft[38] and waste collection data was taken from the Environment Agency's WRATE (2008)[39].

[35] *European Aluminium Association (2008) Environmental Profile Report for the European Aluminium Industry*

[36] *DEFRA/DECC (2010). Greenhouse gas Conversion Factors. Available at: http://www.defra.gov.uk/environment/business/reporting/pdf/100805-guidelines-ghg-conversion-factors.pdf*

[37] *Swiss Centre for Life Cycle Inventories (2010) Ecoinvent Version 2.2*

[38] *CE Delft (2007) Environmental Indices for the Dutch Packaging Tax*

[39] *Environment Agency (2008) WRATE Version 1*

The table contains additional information, such as a column for a carbon factor relating to preparation for reuse, which is not used as part of the Carbon Metric at present. Some of the waste management options are not appropriate to aluminium, such as energy recovery to anaerobic digestion. However, these options will be appropriate for other waste streams such as food and garden waste. This information is provided to allow future development of the Carbon Metric to consider additional issues if required. Further discussion is provided in Section 8.2.

The calculation of the Carbon Factors allows the environmental impact of different end of life choices to be compared. A negative Carbon Factors indicates that this option has a beneficial effect on the environment by lowering expected emissions. This is expected from processes at the top of the waste hierarchy, such as waste prevention. Positive Carbon Factors indicate processes which have an adverse impact on the environment. The example of aluminium given in Table 6.1 and the accompanying calculations shows the environmental impact between preventing aluminium waste and all other options is much more significant than the difference between recycling and disposing of aluminium waste. As such, waste strategies for aluminium will have the greatest environmental impact if they focus on waste prevention rather than recycling or disposal options.

6.1.3 Variations from the standard calculation

The following assumptions have been made about the segregation for key materials into different end of life options:

- For colour separated glass, the benefit of recycling shown is based on this being sent to remelt for closed loop recycling. For glass which is mixed colour, data from Valpak suggests 44% is used in place of aggregate and 56% is used in remelt applications in the UK and abroad. The impact of recycling mixed glass is based on this split.
- For food, both anaerobic digestion and composting are identified as separate options. For garden waste, the same options have also been shown. However, due to its composition, garden waste is not suited to the same anaerobic digestion process as food waste. It requires a 'dry' AD system. At the time of writing no such systems exist in Scotland. However, data is presented for this eventuality. Mixed food and garden waste is modelled as being sent to a 'wet' AD system. More details are given in Annex 3. In both cases, the recycling route selected is not closed loop (i.e. it does not avoid food or garden plants). The calculation therefore excludes the impacts associated with earlier life cycle stages.
- Information on the reuse and recycling of textiles was obtained from the Zero Waste Scotland report on the Composition of municipal solid waste in Scotland (2010)[40]. The report suggests that 46% of textiles arising in Scotland MSW in 2009 was reusable, 32% was non-reusable textiles and 22% was shoes, belts and bags.
- For wood, the typical recycling route is conversion to particleboard[41]. Therefore, rather than compare to average recycling, the calculation assumes that recyclate is sent to this market.
- For plastics the impact of forming is excluded from the calculation of the benefits of recycling. Although prevention of plastic waste would prevent emissions from this stage, products made from recycled materials require forming, and so the calculation follows a non-standard format to allow for this. The average plastics factor is based on the split of polymers used in UK packaging identified by AMA research (2009)42.
- For electrical items, the calculation is based upon data sourced from Huisman (2008)34 which presents data on the benefit of recycling WEEE, but not total impacts. Although the figures contained are of good quality, they do not match the format of the other figures used in this report.
- For post-consumer batteries the same issue as WEEE exists, that the benefit of recycling, but not the total impact, can be identified from the literature.

The accompanying Guidance Report contains further detail for each material. How each value was derived for each material can be seen, as well as the specific data sources, where sources are freely available.

6.2 From Carbon Factors to Weightings

The Carbon Factors were translated into a set of ranked weightings. The weightings were scaled between 0 and 100, giving the product with the highest environmental impact, textiles, a weighting value of 100 and ranking all other materials and products relative to this.

Table 6.2 Carbon Factors and Weighting for each material and product in the Carbon Metric

[40] *ZWS (2010) The Composition of Municipal Solid Waste in Scotland. Available from:* *http://www.wrap.org.uk/downloads/Scotland_MSW_report_final.67a78687.8938.pdf*

[41] *WRAP (2009)* Wood Waste Market In The UK *WRAP; Banbury*

[42] *AMA Research (2009)* Plastics Recycling Market UK 2009-2013*, AMA Research; Cheltenham*

Waste Stream	Carbon Factor	Carbon Weighting
Textiles	-14069	100.00
Textiles and Footwear	-11916	84.70
Aluminium cans and foil	-9267	65.87
Footwear	-4385	31.17
Mixed Cans	-3911	27.80
Scrap Metal	-2261	16.07
Steel Cans	-1723	12.25
PET (including forming)	-1705	12.12
WEEE - Small	-1482	10.54
WEEE - Mixed	-1374	9.77
WEEE - Large	-1266	9.00
PS (including forming)	-1240	8.81
Wood	-1224	8.70
Average Plastics	-1205	8.57
Average plastic rigid (including bottles)	-1204	8.56
HDPE (including forming)	-1161	8.25
LDPE and LLDPE (including forming)	-1098	7.80
Average plastic film (including bags)	-1076	7.65
PP (including forming)	-948	6.74
PVC (including forming)	-888	6.31
Board	-820	5.83
Mixed paper and board	-799	5.68
Paper	-736	5.23
Books	-736	5.23
Mineral Oil	-725	5.15
WEEE - Fridges and Freezers	-656	4.66
Food and Drink Waste (wet AD)	-612	4.35
Food and Drink Waste (Composting)	-489	3.48
Batteries (Post Consumer Non Automotive)	-487	3.46
Glass (colour separated)	-392	2.78
Mixed Food and Garden Waste (dry AD)	-380	2.70
Garden Waste (dry AD)	-331	2.35
Mixed Food and Garden Waste (Composting)	-296	2.10
Garden Waste Composting	-255	1.81
Glass (mixed colours)	-223	1.58
Plasterboard	-139	0.99
Aggregates (Rubble)	-4	0.03

PET - Polyethylene terephthalate
HDPE - High-density polyethylene
LDPE - Low-density polyethylene
LLDPE - Linear Low-density polyethylene
WEEE - Waste Electrical and Electronic Equipment
PP - Polypropylene
PVC - Polyvinyl Chloride

6.3 The Carbon Metric Calculation

The final step in the calculation of the Carbon Metric is to transform the weightings for each material and product. The total environmental impact for each material or product depends, not only on the emissions created from one unit of the item, but the amount of waste produced. In order to calculate the total environmental impact within the waste stream for a material or product an understanding of the waste composition is required together with the total volume of waste, the amount of each material recycled and the recycling route (closed or open loop). Carbon Metric performance monitoring will be based upon the National Waste Composition for MSW in Scotland data developed by Zero Waste Scotland, however individual Local Authorities may opt to use local waste composition data where this reports the same materials types as the National study.

In order to calculate Carbon Metric Performance, the following two calculations must be applied. The first establishes the Total Carbon Content in the waste stream. The Total Carbon Content is equal to the sum of each individual waste stream multiplied by its associated carbon weighting.

$$\text{Total Carbon Content} = \text{Sum for all materials in waste stream} \left(\text{Total tonnage of individual material in waste stream} \times \text{Associated carbon metric weighting} \right)$$

In order to establish the Carbon Metric recycling rate of an individual material, the second calculation should be made.

$$\text{Total metric recycling rate} = \frac{\left(\text{Total tonnage of individual material recycled} \times \text{Associated carbon metric weighting} \right)}{\text{Total carbon content}} \times 100$$

For materials with different possible recycling routes the material should be weighted using the route to which it was actually sent. In order to calculate the total recycling performance rate, this calculation is repeated and combined for all materials. In this way, the Carbon Metric can be calculated for different materials and products. For further information on how to use the Carbon Metric please refer to the Guidance Report.

7.0 The Carbon Trust Review

The Carbon Trust undertook a peer review of the data and methodology used to create the Carbon Metric. The primary aim of the review was to assess the suitability of the methodology, including the data used and the implementation mechanism, to satisfactorily reflect the carbon impacts of various waste management options.

The review concluded that:

> "The Carbon Metric provides a clear methodology to define and monitor recycling targets with reference to their environmental impact. This Metric complements the current weight-based targets, providing a better steer and incentives to choose the most appropriate waste management techniques available for each material."

A full copy of the Carbon Trust review can be accessed on the Zero Waste Scotland website.

8.0 Conclusion

8.1 Summary

This report has given technical background information on the creation of the Carbon Metric. The report has introduced the concept of Life Cycle Assessment and Life Cycle thinking and explained how these concepts have contributed to the methodology of the Carbon Metric. The scope and methodology have been discussed in detail and data sources, quality issues and anomalies explained. Finally, the construction of the Carbon Metric itself, through the assembly of Carbon Factors and weightings has been discussed.

Further information on how to use the Carbon Metric is given in the Guidance Report and the Carbon Metric Calculator.

8.2 Recommendations for development of the Zero Waste Plan Carbon Metric

Although this methodology currently relies on secondary data mainly from a European level, the use of primary Scottish data would be preferred, and is likely to play an increasingly important role in the Zero Waste Plan. Zero Waste Scotland is aware of plans to update the following factors, which should be incorporated into the Carbon Metric:

- Information on the impacts of reusing furniture and electrical items from a Zero Waste Scotland project;
- Data on the environmental impact of the manufacture of glass and plastics.

The Scottish Government is committed to introducing landfill bans for certain materials. By providing factors in transparent format, the factors are safeguarded for future data developments to a degree as the calculation can be amended to account for changes such as landfill bans, without affecting the other factors within the calculation. This transparency will also facilitate a wider understanding of the effect of landfill bans.

In future, the scope of the Carbon Metric could be altered to consider alternative options (e.g. impact of prevention versus landfill). The format of the data provided allows the Carbon Metric to be expanded in future should this support Scottish Government policy.

Annex 1 Energy from Waste

A range of energy recovery technologies exist which could convert materials to energy at end of life. These include combustion (electricity only or combined heat and power), gasification, pyrolysis and anaerobic digestion.

Despite the potential for the different technologies, combustion with electricity generation is the most prevalent technology, and will continue to be in the short term.

The efficiency with which the incinerator converts energy in the waste into electricity is an important factor affecting the results of this study, as it determines to what degree the impacts of the incineration process are offset by avoiding the need to produce electricity from primary fuels. Published studies give a wide range of values for the efficiency of power generation from municipal waste incinerators.

This variation arises due to a number of factors including:

- Type and nature of the waste feedstock;
- Output options – potential to use electricity, water, steam produced;
- Technology applied;
- Whether internal energy consumption of the process is accounted for;
- Whether gross calorific values (GCV) or net calorific values (NCV) are used in the calculations (in some reports it is not clear which is used).

Examples of values quoted in recent studies are given below:

- A 2006 study by the United States Environmental Protection Agency (USEPA)[43] gives an efficiency of 17.8% for electricity generated from mass burn incineration (not clear whether these figures are based on NCV or GCV).

- A 2001 report for the European Commission[44] indicates that efficiencies for power generation range from 15–22% in thermal treatment plants based on NCV.

- The 2006 BAT standard for incineration[45] quotes efficiencies ranging from 15-30% for thermal plants producing electricity only (not clear whether these figures are based on NCV or GCV).

- A 2003 Biffaward study carried out by C-Tech Innovation[46] reports a figure of 25.4% based on NCV.

- Fichtner, in a 2004 report[47] for ESTET, state that "For a modern plant based combustion technology, the net electrical efficiency is in the range 19 to 27%" based on NCV.

- A 2003 good-practice guide produced by CIWM[48] reports efficiency of generation of 22%-25% (not clear whether these figures are based on NCV or GCV).

The default assumption for this work is that a conversion efficiency (NCV) of 23%, which is midway between the extremes reported in the literature, is typical for modern incinerators.

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43 USEPA (2006) Solid Waste Management and Greenhouse Gases – A Life-cycle Assessment of Emissions and Sinks, 3rd Edition

44 Smith, A. et al. (2001) Waste Management Options and Climate Change, Final Report to the European Commission

45 European Integrated Pollution Prevention and Control Bureau (2006) Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

46 *C-Tech Innovation for Biffaward (2003) Thermal Methods of Municipal Waste Treatment*

47 Fichtner Consulting Engineers Limited (2004) The Viability Of Advanced Thermal Treatment Of MSW In The UK, ESTET

48 *CIWM (2003) Energy from Waste: A Good Practice Guide, Northampton: IWM Business Services Group*

Annex 2 Approach to Recycling

The Zero Waste Plan methodology is designed to identify the consequences of changes in the system, rather than attribute a footprint to an item or material. Of key interest is the need to highlight the difference in impact between alternative waste management routes, and the potential benefits which closed loop recycling can offer over alternative options. The purpose is to maximise the benefits of waste management options rather than simply moving from one option to another.

In Life Cycle Assessment, ISO 14044 (2006), sets out definitions for closed and open loop recycling as follows:

"a) A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where *no changes* occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. However, the first use of virgin materials in applicable open-loop product systems may follow an open-loop allocation procedure outlined in b).

b) An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

Under example (a), aluminium packaging may be recycled into aluminium packaging or other applications. In either case, where it substitutes for primary aluminium of equivalent quality, the environmental benefit is the same. Where plastic is used in place of wood, an open-loop allocation procedure is more appropriate.

For card products, it is not true to say that all products in one category are recycled back into that category. For example, carton board may be recycled and made into corrugate. Although the fibres may be shortened through the recycling process, the net environmental impact is the same regardless of whether the material goes to corrugate or cartonboard manufacture, and it is therefore inappropriate to only recognise the benefit of one alternative as closed loop in nature.

The methodology assumes that 62.5% of glass is recycled in closed loop applications[49]. The remainder is assumed to be used in aggregates.

Table A2.2 Glass Recycled (2008)

Recyclate collected	Bottle Manufacture UK	Bottle Manufacture Abroad	Aggregates, UK
1,613,000	665,561	337,000*	600,000*

*Approximation

For card and paper, the recycling rate reflects the information provided by the industry on actual performance for different grades of packaging.

[49] *British Glass (2007). Available at: www.britglass.org.uk/NewsEvents/BGNewsCurrent/HanktheSingingBottledraws.html and www.britglass.org.uk/NewsEvents/BGNewsCurrent/GlassRecyclingExceedsExpe.html*

Annex 3 Anaerobic Digestion

The calculation of the greenhouse gas impacts of anaerobic digestion is based upon the following information.

Food and drink waste to anaerobic digestion is assumed to go to a wet system, whilst the garden waste to anaerobic digestion is assumed to go to a dry system. The mixed food, drink and garden waste stream is also assumed to go to a dry anaerobic digestion system, which is based on 17.5% food and drink and 82.5% garden waste.

Food is assumed to be 70% water and 30% dry matter[50] generating 98m^3 of methane per tonne of food waste[51]. Garden waste is assumed to be 47% moisture and 53% dry matter, generating 85m^3 of methane per tonne of garden waste[52]. 3% of methane is assumed to escape as fugitive emissions.

For both the food and drink anaerobic digestion system and the garden waste anaerobic digestion system the methane, at a calorific value of 35.8 MJm[53], has then been assumed to be converted to electricity at a conversion efficiency of 37%. Of the electricity produced, 15% is assumed to have been fed back into the process.

The net electricity output has then been contrasted to the grid rolling average for 2008[54] to identify avoided greenhouse gas emissions associated with electricity production.

Avoided landfill emissions are as described in Section 4.5.

The digestate is assumed to be used in agricultural applications replacing fertiliser. Using factors identified in Williams et al (2006)[55].

In 2007/08, the UK consumed 1.6 million tonnes of fertilizer, of which two thirds was nitrogen fertilizer[56]. The main market for this is use in agriculture.

Williams et al (2006)[50] identify the following emissions from the manufacture of nitrogen, phosphorous and potassium.

Table A3.1 Emissions from the Manufacture of Fertilisers

Fertiliser	kg CO_2 eq per kg fertiliser
Nitrogen (N)	6.8
Phosphorous (P)	1.2
Potassium (K)	0.5

[50] *Bingemer, H.G. and P.J. Crutzen, (1987) The production of methane from solid wastes. J. Geophys. Res., 92 (D2), 2181-2187*

[51] *WRAP calculation*

[52] *Mitaftsi, O and Smith, S R (2006) Quantifying Household Waste Diversion from Landfill Disposal by Home Composting and Kerbside Collection, Imperial College, London*

[53] *Zaher, U., Khachatryan, H.; Ewing, T.; Johnson, R.; Chen, S.; Stockle, C.O. (2010) Biomass assessment for potential bio-fuels production: Simple methodology and case study, The Journal of solid waste technology and management vol:36 iss:3 pg:182 -192*

[54] *DEFRA/DECC (October 2010) Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting. Available at: http://www.defra.gov.uk/environment/economy/business-efficiency/reporting*

[55] *Williams AG, Audsley E and Sandars DL (2006). Determining the Environmental Burdens and Resource Uses in the Production of Agricultural and Horticultural Commodities. Main Report. DEFRA Research Project IS0205. Bedford: Cranfield University and DEFRA*

[56] *Agricultural Industries Confederation (2009) Fertiliser Statistics 2009 Report, AIC, Peterborough. Available at: www.agindustries.org.uk/document.aspx?fn=load&media_id=3625&publicationId=350*

When used in place of fertilizer, compost is used based upon its available nutrient content.

When identifying the quantity of nitrogen within biowaste products, it is important to note that the total nitrogen in compost and other biowaste products is not an indication of how much nitrogen will become available with time[57] . Unlike fertiliser, compost and digestate release nitrogen over a number of years, reducing N_2O emissions relative to fertiliser application. Some discussions and recommendations with regard to nutrient availability are set out in a recent WRAP literature review. In 2006, the following formula was proposed for predicting nitrogen availability from composted materials:

'The nitrogen available to crops equals the percentage of total N as water extractable N (e.g. 1%), plus the mineralisable N based on C/N ratio. Half of the potential available nitrogen may be expected to be released in year one, with the remainder in years two and three'[58].

The 'fertiliser equivalent' for compost nitrogen varies with feedstock, but can be up to 25% over 3 years[59]. Potassium is readily available in compost in water extractable and exchangeable forms, and can be taken to be 80 % available. Phosphate is 85% available in inorganic fertiliser.

Using the factors from Williams et al (2006)[50] for fertiliser production, the following estimates are made of the benefit of sending 1 tonne of food or food and garden waste to anaerobic digestion.

Table A3.2 Greenhouse Gas emissions avoided per tonne of food or food and garden waste sent to Anaerobic Digestion

	kg CO_2eq avoided per tonne of input material, fertiliser displacement	kg CO_2eq avoided via energy generation	Total kg CO_2eq avoided per tonne of input material
1 tonne green & food waste digestate (not stabilised)	6.8	140	147 (150 including liquor)
1 tonne of food waste to digestate (not stabilised)	3.3	154	157 (160 including liquor)
Liquor from AD process (1 tonne of food or green waste input)	3	Within digestate figures	Within digestate figures

[57] WRAP (2006) *Production of Guidelines for Using Compost in Crop Production – A Brief Literature Review. Enviros Consulting Ltd report for WRAP, Banbury*

[58] WRAP (2006) *Production of Guidelines for Using Compost in Crop Production – A Brief Literature Review. Enviros Consulting Ltd report for WRAP, Banbury*

[59] Prasad, M (2009) *EPA STRIVE Programme 2007-2013 A Literature Review on the Availability of Nitrogen from Compost in Relation to the Nitrate Regulations SI 378 of 2006 Small Scale Study Report* Environmental Protection Agency, Ireland

Annex 4 Data Sources

Material	Reference	
	Raw material extraction, processing and transport	**Waste Management Impacts**
Aluminium cans and foil	European Aluminium Association (2008) *Environmental Profile Report for the European Aluminium Industry*, European Aluminium Association	WRATE (2005)
Steel Cans	Estimate based on data from World Steel Life Cycle Inventory (2009), BOF route, 1kg , weighted average, EU, World Steel Association, Brussels	WRATE (2005)
Mixed Cans	Estimate based on aluminium and steel data.	WRATE (2005)
Glass	Enviros (2003) *Glass Recycling - Life Cycle Carbon dioxide Emissions*; British Glass, Sheffield	
Wood	Corrim (2005 & 2010) *Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction*; Corrim, Seattle WRAP (2009) *Life Cycle Assessment of Closed Loop MDF Recycling*; WRAP, Banbury	WRAP (2009) *Life Cycle Assessment of Closed Loop MDF Recycling*; WRAP, Banbury Gasol C., Farreny, R., Gabarrell, X., and Rieradevall, J., (2008) Life cycle assessment comparison among different reuse intensities for industrial wooden containers *The International Journal of LCA* Volume 13, Number 5, 421-431 Merrild, H., and Christensen, T.H. (2009) Recycling of wood for particle board production: accounting of greenhouse gases and global warming contributions *Waste Management and Research* (27) 781-788 WRATE (2005)
Aggregates (Rubble)	WRAP CO_2 Emissions Estimator Tool Environment Agency (2007) Construction Carbon Calculator	
Paper	Ecoinvent v2.0 (2007) Swiss Centre for Life Cycle Inventories	*Ecoinvent v2.0* (2007) Swiss Centre for Life Cycle Inventories
Books	Estimate based on paper	
Board	FEFCO (2009) *European Database for Corrugated Board Life Cycle Studies*, FEFCO Procarton (2009) *Carbon Footprint for Cartons*, Zurich, Switzerland	*Ecoinvent v2.0* (2007) Swiss Centre for Life Cycle Inventories
Mixed paper and board	Estimate based on above	
Scrap Metal	British Metals Recycling Association (website) Ecoinvent v2.0 (2007) Swiss Centre for Life Cycle Inventories	Ecoinvent v2.0 (2007) Swiss Centre for Life Cycle Inventories WRATE (2005)
Incinerator Residues (Non Metal)	To be identified	To be identified
Automotive Batteries	To be identified	To be identified
WEEE - Fluorescent	To be identified	To be identified

Material	**Reference**	
	Raw material extraction, processing and transport	**Waste Management Impacts**
Tubes		
WEEE - Fridges and Freezers	ISIS (2008) Preparatory Studies for Eco-design Requirements of EuPs (Tender TREN/D1/40-2005) LOT 13: Domestic Refrigerators & Freezers	ISIS (2008) Preparatory Studies for Eco-design Requirements of EuPs (Tender TREN/D1/40-2005) LOT 13: Domestic Refrigerators & Freezers WRATE (2005)
Food and Drink Waste	Several data sources used to estimate food production impacts. Agriculture UNFCCC website Fertiliser production: Wood., S and Cowie, A., (2004) *A Review of Greenhouse Gas Emission Factors for Fertiliser Production* Research and Development Division, State Forests of New South Wales. Cooperative Research Centre for Greenhouse Accounting Food Manufacture, Transport, Catering and Home Related Impacts: Brook Lyndhurst (2009) *London's Food Sector Greenhouse Gas Emissions*, GLA Retail: Tassou (2008) FO0405 *Greenhouse Gas Impacts of Food Retailing*, DEFRA	AFOR (2009) *Market survey of the UK organics recycling industry - 2007/08*; WRAP, Banbury (Substitution rates for compost) Williams AG, Audsley E and Sandars DL (2006) *Determining the Environmental Burdens and Resource Uses in the Production of Agricultural and Horticultural Commodities. Main Report. IS0205*, DEFRA (avoided fertiliser impacts) Kranert, M. & Gottschall (2007) *Grünabfälle – besser kompostieren oder energetisch verwerten?* Eddie (information on peat) DEFRA (unpublished) (information on composting impacts)
Garden Waste	-	
Plastics:		
LDPE and LLDPE (excel forming)	Boustead (2005) *Eco-profiles of the European Plastics Industry Low Density Polyethylene* (LDPE). Plastics Europe, Brussels	WRAP (2008) LCA of Mixed Waste Plastic Management Options; WRAP, Banbury
HDPE (excel forming)	Boustead (2005) *Eco-profiles of the European Plastics Industry High Density Polyethylene* (HDPE). Plastics Europe, Brussels	WRAP (2010) LCA of Example Milk Packaging Systems; WRAP, Banbury
PP (excel forming)	Boustead (2005) *Eco-profiles of the European Plastics Industry Polypropylene* (PP). Plastics Europe, Brussels	WRAP (2008) LCA of Mixed Waste Plastic Management Options; WRAP, Banbury
PVC (excel forming)	Boustead (2005) *Eco-profiles of the European Plastics Industry Polyvinyl Chloride* (PVC) (Suspension). Plastics Europe, Brussels	WRAP (2008) LCA of Mixed Waste Plastic Management Options; WRAP, Banbury
PS (excel forming)	Boustead (2005) *Eco-profiles of the European Plastics Industry Polystyrene (High Impact)* (HIPS). Plastics Europe, Brussels	PWC (2002) *Life Cycle Assessment of Expanded Polystyrene Packaging*, Umps
PET (excel forming)	Boustead (2005) *Eco-profiles of the European Plastics Industry Polyethylene Terephthalate* (PET). Plastics Europe,	WRAP (2010*) LCA of Example Milk Packaging Systems*, WRAP, Banbury

Material	**Reference**	
	Raw material extraction, processing and transport	**Waste Management Impacts**
	Brussels	
Average plastic film (inch bags)	Based on split in AMA Research (2009) *Plastics Recycling Market UK 2009-2013*, UK; Cheltenham	WRAP (2008) *LCA of Mixed Waste Plastic Management Options*; WRAP, Banbury
Average plastic rigid (inch bottles)		
Clothing	BIO IS (unpublished data)	Arrant (2008) *Environmental Benefit from Reusing Clothes*, WRATE (2005)
Footwear	Albers, K., Canapé, P., Miller, J. (2008) *Analysing the Environmental Impacts of Simple Shoes*, University of Santa Barbara, California	
Furniture	To be updated following pending Zero Waste Scotland research	
WEEE – Large	Huisman, J., et al (2008) *2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment* – Study No. 07010401/2006/442493/ETU/G4, United Nations University, Bonn Germany	
WEEE – Mixed		
WEEE – Small		
Batteries (Post Consumer Non-Automotive)	-	DEFRA (2006) *Battery Waste Management Life Cycle Assessment*, prepared by ERM; WRAP, Banbury
Paint	Althaus et al (2007) *Life Cycle Inventories of Chemicals, Final report Ecoinvent data v2.2*; ESU Services, Switzerland CBI (2009) Market Survey The paints and other coatings market in the United Kingdom; CBI, The Netherlands	-
Vegetable Oil	Schmidt, J (2010) Comparative life cycle assessment of rapeseed oil and palm oil *International Journal of LCA*, 15, 183-197 Schmidt, Jannick and Weidema, B., (2008) Shift in the marginal supply of vegetable oil *International Journal of LCA*, 13, 235-239	
Mineral Oil	IFEU (2005) *Ecological and energetic assessment of re-refining used oils to base oils: Substitution of primarily produced base oils including semi-synthetic and synthetic compounds*; GEIR	
Plasterboard	WRAP (2008) *Life Cycle Assessment of Plasterboard,* prepared by ERM; WRAP; Banbury	

Annex 5 Material Substitution Rates for Recycling

Finished primary material	Amount of primary materials saved per tonne recycled (tonnes)*	References
Aluminium (cans and foil)	0.943	EAA (2008) Aluminium use in Europe - Country profiles - 2005-2008
Steel cans	0.917	World Steel Life Cycle Inventory (2009) EAF steel slab
Mixed cans	0.925	EAA (2008) Aluminium use in Europe - Country profiles - 2005-2008 and World Steel Life Cycle Inventory (2009) EAF steel slab
Glass (containers and aggregates production)	1.000	Cook, R.F. (1978) The collection and recycling of waste glass (cullet) in glass container manufacture, Conservation & Recycling Volume 2, Issue 1, 1978, Pages 59-69
Wood (general)	1.000	Lack of data so conversion factor assumed to be 1
Aggregates	1.000	Lack of data so conversion factor assumed to be 1
Plastics (general)	0.628	WRAP (2008) LCA of Mixed Waste Plastic Management Options
Recycled plastics replacing virgin plastic granules	0.666	WRAP (2008) LCA of Mixed Waste Plastic Management Options
Recycled plastics replacing virgin sawn timber	0.420	WRAP (2008) LCA of Mixed Waste Plastic Management Options
Paper (all types)	0.800	WRAP (2006) The environmental benefits of recycling
Scrap metals	Not identified	
Incinerator residue	Not identified	
Automotive batteries	Not identified	
Plastics: HDPE replacing virgin HDPE	0.833	WRATE, Waste and Resources Assessment Tool for the Environment (http://www.environment-agency.gov.uk/research/commercial/102922.aspx)
Plastics: Polypropylene replacing polypropylene	0.666	WRAP (2008) LCA of Mixed Waste Plastic Management Options
Fluorescent tubes	Not identified	
Fridges and freezers	Not identified	
Green waste compost replacing peat	0.350	WRAP (2003) Compost and Growing Media Manufacturing in the UK, Opportunities for the Use of Composted Materials. WRAP Research Report, Banbury

Digestate replacing peat	0.380	Fuchs, J.G., (2008) Pres.Nr. 19 Effects of digestate on the environment and on plant production - results of a research project ECN/ORBIT e.V. Workshop 2008 "The future for Anaerobic Digestion of Organic Waste in Europe"
Green waste compost replacing fertiliser (per tonne of green waste in)	0.007 Nitrogen 0.0005 Phosphorous	Williams AG, Audsley E and Sandars DL (2006) *Determining the Environmental Burdens and Resource Uses in the Production of Agricultural and Horticultural Commodities. Main Report. IS0205*, DEFRA (avoided fertiliser impacts)
Digestate replacing fertiliser (per tonne of food in)	0.010 Nitrogen 0.0013 Phosphorous	
Textiles	0.952	DEFRA (2009) Maximising Reuse and Recycling of UK Clothing and Textiles EV0421 - Appendix I - Technical Report
Footwear	0.901	SMART (2007) Recycling of Footwear Products – A Position Paper Prepared by Centre for Sustainable Manufacturing and Reuse/recycling Technologies (SMART) – Loughborough University
Furniture	Not identified	
WEEE - Large domestic appliances	Not identified	
WEEE - Mixed domestic appliances	Not identified	
WEEE - Small domestic appliances	Not identified	
Post-consumer, non-automotive batteries	1.000	Not identified
Paint	0.877	Community RePaint Annual Survey (http://www.communityrepaint.org.uk/)
Vegetable oil	0.787	BIO IS (2010) BIO IS for ADEME ; Ministère de l'Ecologie, de l'Energie, du Développement Durable et de la Mer ; Ministère de l'Alimentation, de l'Agriculture et de la Pêche, and France Agrimer – Analyses de Cycle de Vie appliquées aux biocarburants de première génération consommés en France
Mineral oil	1.000	Not identified
Plasterboard	1.000	ERM (2008) Technical Report for WRAP – Life Cycle Assessment of Plasterboard – Quantifying the environmental impacts throughout the product life cycle, building the evidence base in sustainable construction

* The system boundary for the virgin material is one tonne of finished virgin material – overburden from upstream processes are excluded

Annex 6 Greenhouse Gas Conversion Factors

Industrial Designation or Common Name	**Chemical Formula**	**Lifetime (years)**	**Radiative Efficiency (Wm^{-2} ppb^{-1})**	**Global Warming Potential with 100 year time horizon (previous estimates for 1st IPCC assessment report)**	**Possible source of emissions**
Carbon dioxide	CO_2	Variable	1.4×10^{-5}	1	Combustion of fossil fuels
Methane	CH_4	12	3.7×10^{-4}	25 (23)	Decomposition of biodegradable material, enteric emissions.
Nitrous Oxide	N_2O	114	3.03×10^{-3}	298 (296)	N_2O arises from Stationary Sources, mobile sources, manure, soil management and agricultural residue burning, sewage, combustion and bunker fuels
Sulphur hexafluoride	SF_6	3200	0.52	22,800 (22,200)	Leakage from electricity substations, magnesium smelters, some consumer goods
HFC 134a (R134a refrigerant)	CH_2FCF_3	14	0.16	1,430 (1,300)	Substitution of ozone depleting substances, refrigerant manufacture / leaks, aerosols, transmission and distribution of electricity.
Dichlorodifluoro-methane CFC 12 (R12 refrigerant)	CCl_2F_2	100	0.32	10900	
Difluoromono-chloromethane HCFC 22 (R22 refrigerant)	$CHClF_2$	12	0.2	1810	

No single lifetime can be determined for carbon dioxide because of the difference in timescales associated with long and short cycle biogenic carbon. For a calculation of lifetimes and a full list of greenhouse gases and their global warming potentials please see:

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor and H.L. Miller (eds.) (2007) *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, United Kingdom Table 2.14. *Lifetimes, radiative efficiencies and direct (except for CH4) global warming potentials (GWP) relative to* CO_2. Available at: http://www.ipcc.ch/ipccreports/assessments-reports.htm

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