Circular Economy

June 2015

The Carbon Impacts of the Circular Economy

Technical Report

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Contents

Inspiring change for Scotland’s resource economy

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1 Executive Summary

This project uses Scotland's ground-breaking Carbon Metric, as well as other peer reviewed research conducted by Zero Waste Scotland, to quantify the potential carbon impacts of a more circular economy in Scotland.

The report's key findings are:

1. **Material consumption** is responsible for over two thirds of Scotland's carbon emissions.
2. **A more circular Scottish economy** could reduce *territorial emissions* by 11 million tonnes CO2e per year by 2050 compared to BAU, while providing continued economic growth.
3. **Nearly 1 in every 5 tonnes** of material flowing through the Scottish economy is waste.
4. **Regardless of carbon accounting methodology** (*territorial* vs. *consumption*), a more circular could significantly reduce Scotland's carbon footprint without sacrificing economic prosperity.

The methodology used to arrive at these findings involved the creation of a baseline to assess the carbon impacts of Scotland's material consumption in 2012. This was subsequently used to compare the carbon impacts of four different economic scenarios for 2050, each characterized by different levels of material circularity. These 2050 scenarios do not predict the future; rather they have been designed to highlight the carbon reductions that could be possible with a more circular Scottish economy.

This project is the first attempt to quantify the carbon impacts of a circular economy in Scotland and is one of the first globally to quantify the environmental impacts of the circular economy at a national scale. Decision makers should consider the uncertainties which are inherent to any new area of study when drawing conclusions from the results. The analysis represents a bespoke approach, drawing on a life cycle thinking method to give an initial, high level description of the possible carbon impacts of a circular economy in Scotland. This life cycle approach could be built on and strengthened in the future, using input output analysis for example, to understand the potential impacts and opportunities of a more circular economy in greater detail.

1.1 Carbon Accounting

The carbon impacts of material consumption can be quantified using either *territorial* or *consumption* based accounting methods. *Territorial accounting*, also known as *producer-based accounting*, centres on the idea of 'producer responsibility' – it only considers emissions produced within a region or country. In contrast, *consumption accounting* is based on the idea of 'consumer responsibility'; it includes all the emissions resulting from consumption, regardless of where those emissions are generated.

The results of this study are presented in both *territorial* and *consumption* terms to illustrate the importance of selecting the appropriate carbon accounting approach when making policy decisions.

1.2 2012 Baseline

This study found that in 2012 Scotland consumed about 60.4 million tonnes (Mt) of material, equivalent to 11.4 tonnes of material per person, 43% (26Mt) of which was imported. Over 11.7Mt of material was wasted, the equivalent to 2.2t of waste per person. This is comparable to other UK and EU nations. Using *territorial* accounting, the carbon impacts of Scotland's material consumption in 2012 is estimated at 36MtCO2eq. Using *consumption* accounting, the figure is 57MtCO2eq. Table 1 below shows these figures as a proportion of Scotland's overall carbon footprint, illustrating the substantial carbon impacts of material use. New opportunities for Scotland to reduce both *territorial* and *consumption* based carbon footprints could be explored by policy makers through a circular economy strategy.

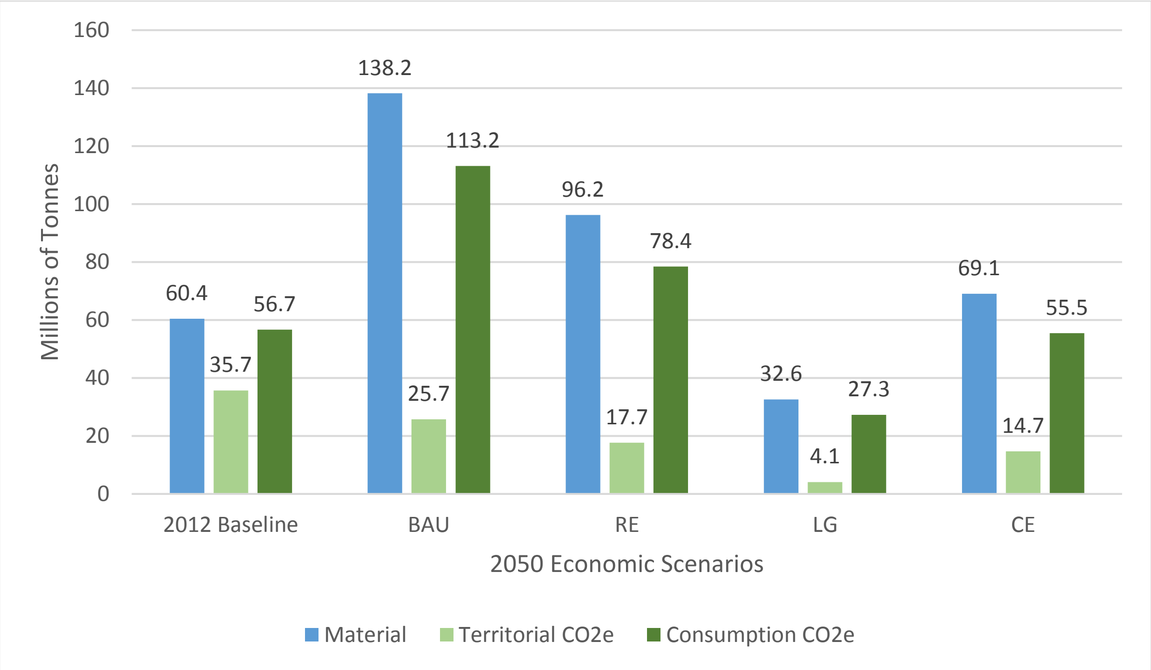
Table 1. The *territorial* and *consumption* carbon impacts of material consumption for Scotland, as a proportion of overall carbon impacts

Carbon accounting boundary	Material carbon footprint (2012)	Total carbon footprint	Material carbon footprint as a proportion of total[1]
Territorial carbon footprint	36 MtCO2eq (6.7 tCO2eq/capita)	53 MtCO2eq (2012)[2]	68%
Consumption carbon footprint	57 MtCO2eq (10.7 tCO2eq/capita)	77 MtCO2eq (2012)[3]	74%

1.3 2050 Scenarios

Graph 1 shows the carbon impacts of material consumption in 2012 compared to four 2050 scenarios: Business as Usual (BAU), Resource Efficiency (RE); Limited Growth (LG) and Circular Economy (CE).

Graph 1. *Territorial* and *consumption* carbon impacts for 2012 and the 2050 scenarios for material consumption in Scotland



Graph 1 shows that a CE could significantly reduce carbon emissions compared to a BAU scenario in both *territorial* and *consumption* terms. These results illustrate how a more circular Scottish economy can strengthen Scotland's existing carbon reduction strategy and provide additional avenues for achieving its ambitious climate change targets.

In *consumption* terms, the circular economy scenario offers substantial carbon savings (57.7 MtCO2eq) compared to BAU and has a similar carbon impact to 2012 material consumption impacts,

[1] This calculation should be treated with caution as it combines data from multiple datasets with different boundaries. It should be used as an indication of scale, rather than an accurate estimate.
[2] Scottish Government (2014). Scottish Greenhouse Gas Emissions 2012. http://www.gov.scot/Resource/0045/00452084.pdf
[3] Scottish Government (2015). Scotland's Carbon Footprint 1998-2012. http://www.gov.scot/Resource/0047/00472991.pdf

despite annual growth of 2.2% to 2050. The *territorial* impacts of the circular economy scenario are also lower than 2012 levels. This indicates that through a more circular economy, it is possible to reduce carbon emissions in Scotland without sacrificing economic growth, so long as that economic activity also achieves material consumption savings. This follows a recent report published by ZWS which found that expanding the remanufacturing sector (a key component of a more circular economy) would result in net job growth for Scotland.[4]

A set of case studies have been developed as a supplement to this study which support the conclusions of the national level results with examples of the carbon impact of circular economy scenarios for specific material types such as steel and rare earth metals. These case studies suggest that circular economy solutions can offer substantial carbon savings at a global scale, even if emissions within Scotland are increased compared to non-circular alternatives. Such considerations may be particularly important when considering materials which are commonly imported to Scotland today, rather than manufactured or disposed of domestically. The quality of available data is better at the material level compared to the data used to create the national level study. So, whilst the national level study described in this technical report gives policy makers their first opportunity to consider the carbon impacts of a circular economy for Scotland, the material specific report and case studies offer some additional reassurance in the quality of these results at a more detailed level. These resources will be forthcoming on the Zero Waste Scotland website[5].

Policy makers concerned about the environmental impacts of Scotland's material consumption should consider *consumption* as well as *territorial* carbon impacts to support their decision making. This project shows that a more circular Scottish economy could provide substantial carbon savings, both in *territorial* and *consumption* terms, without compromising economic growth.

[4] ZWS (2015) Circular Economy Evidence Building Programme: Remanufacturing Study. http://www.zerowastescotland.org.uk/sites/files/zws/Remanufacturing%20Study%20-%20Full%20Report%20-%20March%202015_0.pdf

[5] ZWS (2014) Carbon Impacts of the Circular Economy, Material Specific Report and Case Studies http://www.zerowastescotland.org.uk/

2 Introduction

Scotland has ambitions to become a more circular economy, where our resources are used efficiently and kept circulating within the economy for as long as possible compared to today's linear economy. The circular economy will involve more remanufacturing, repair and reprocessing activities taking place in Scotland as well as significant changes in how companies do business and how consumers use products. Initial studies have been conducted by the Scottish Government, Scottish Enterprise, Highlands and Islands Enterprise, SEPA and Zero Waste Scotland, the Green Alliance and the Ellen MacArthur Foundation to understand the economic and job opportunities of circularity [6]. A circular economy offers environmental opportunities, as well as economic and social ones, through reduced material consumption. This project compliments previous economic studies by quantifying the potential carbon impacts of a circular economy in Scotland with the aim of beginning to understand these opportunities and clarify the potential effects on Scotland's *territorial* and global carbon footprint. Using Scotland's Carbon Metric, a model was created to assess the carbon impacts of Scotland's material consumption in 2012 and built on using four scenarios for 2050 which represented different levels of circularity. This report includes a description of the methodology used to develop the project, the main results and uncertainties and draws conclusions for policy makers.

The carbon impacts of a circular economy can be quantified in two ways based on the two main forms of carbon accounting used by policy makers – *territorial* and *consumption* based carbon accounting. These two approaches were expected to produce different results, which could steer policy makers towards different decisions and actions, particularly where the impacts of a decision vary within Scotland compared to global impacts. However, the results of this project, presented in both *territorial* and *consumption* terms, reveal that a more circular Scottish economy can achieve *both* national and global GHG emissions reductions.

This project is the first attempt to quantify the carbon impacts of a circular economy in Scotland and is one of the first studies globally to quantify the environmental impacts of the circular economy at a national scale. Decision makers should consider the uncertainties which are inherent to any new area of study when drawing conclusions from the results. The analysis represents a bespoke approach, drawing on a life cycle thinking method and building on previous peer reviewed research by Zero Waste Scotland, to give an initial, high level description of what the environmental impacts of a circular economy in Scotland may be. This approach could be built on and strengthened in the future, using input output analysis, for example, to understand the potential impacts and opportunities in greater detail.

[6] ZWS (2015). Circular Economy Evidence Building Programme: Remanufacturing Study; Green Alliance (2015). Circular Economy Scotland. http://www.green-alliance.org.uk/circular-economy-scotland.php; EMF (2014) Scotland and the Circular Economy: A preliminary examination of the opportunities for a circular economy in Scotland.
http://www.zerowastescotland.org.uk/sites/files/zws/Scotland%20and%20the%20Circular%20Economy%20%28a%20report%20for%20the%20Scottish%20Government%29.pdf

3 Methodology

The approach taken in this project was a desk-based study which combined tonnage data on material consumption and waste management in Scotland with carbon emissions factors that considered either a global boundary (*consumption*) or a Scottish boundary (*territorial*). A model based on material flows in Scotland in 2012 (which represented the latest available year for the key datasets) was developed. Four scenarios for 2050 were created: the business as usual, resource efficiency, limited growth and circular economy scenarios. These 2050 scenarios varied the production and consumption of material flows in Scotland, modelling different levels of circularity to show how these impact on Scotland's carbon emissions.

Finally, case studies were developed to explore the impacts of using either *consumption* or *territorial* carbon accounting approaches for specific material flow decisions for Scotland. The methodology and results of these case studies will be presented in a separate andforthcoming report[7].

This section of the report summarises the most significant methodological decisions. A more complete and detailed methodology is available in Annex 1 at the end of this report.

3.1 2012 Baseline model

The 2012 baseline model combines data on material flows for domestic production, imports and exports to give an estimation of Scotland's direct material consumption by material type. This data has been scaled down to Scottish levels from UK HMRC data for the imports and exports[8], ONS environmental accounts[9] and various sources including WRAP and ProdCom for the domestic production data. Data on waste management from SEPA[10] was added to the model to indicate how much waste was managed in and outside of Scotland, as well as the proportions of waste recycled, incinerated and landfilled.

This tonnage material flows model was then combined with *consumption* and *territorial* carbon emissions factors for material production and waste (adapted from the Scottish Carbon Metric[11]). The *consumption* model included materials which were consumed by Scotland. So, domestic production, imports and Scottish waste managed inside and outside of Scotland was included, exports and non-Scottish waste managed in Scotland was excluded. The *territorial* model included all the materials produced and wasted in Scotland, regardless of whether those materials were consumed in Scotland or not. Therefore, emissions from production of goods for export and non-Scottish waste managed in Scotland was included but emissions from the production of imported materials and exported wastes were not. The diagrams below summarise the main boundaries of the *consumption* and *territorial* systems.

[7] ZWS (2014) The Carbon Impacts of the Circular Economy: Material Specific Report.
[8] HMRC (2014) UK Trade Data https://www.uktradeinfo.com/Pages/Home.aspx
[9] ONS (2014) Environmental Accounts http://www.ons.gov.uk/ons/rel/environmental/uk-environmental-accounts/2014/stb-stat-bulletin.html
[10] SEPA (2013) Waste Data Tables for 2011 http://www.sepa.org.uk/waste/waste_data.aspx
[11] ZWS (2014) The Scottish Carbon Metric Technical Report http://www.zerowastescotland.org.uk/sites/files/zws/ZWS369Carbon_Metric_Technical_Report2014_Final.pdf

Diagram 3.1 The system boundaries of Scotland's material and waste flows using consumption carbon accounting boundaries

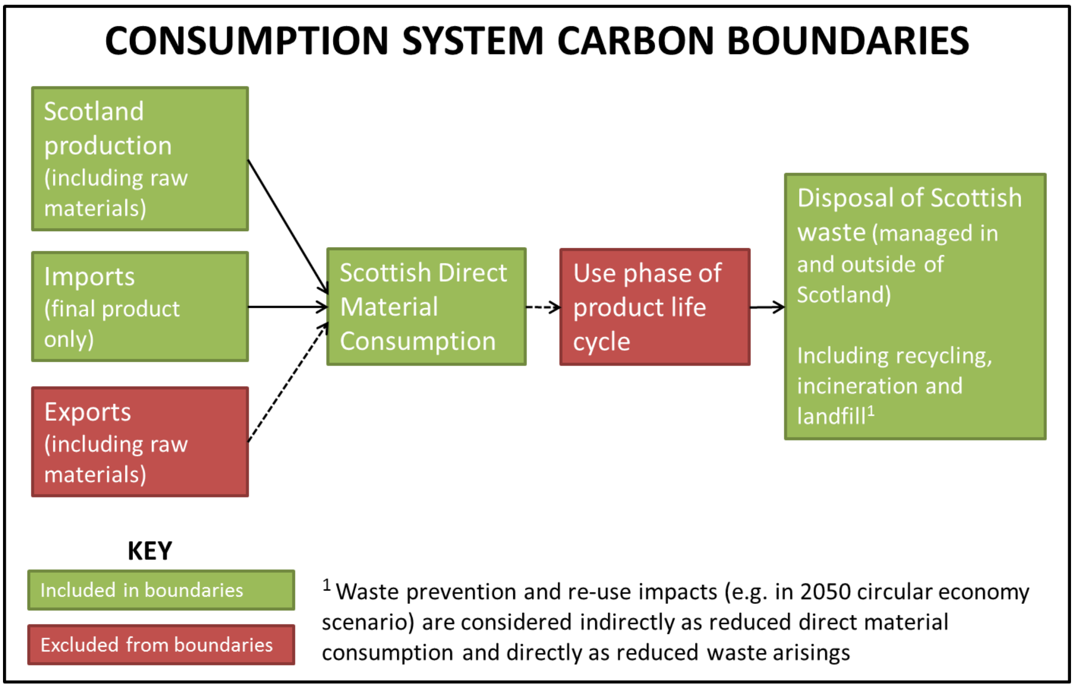
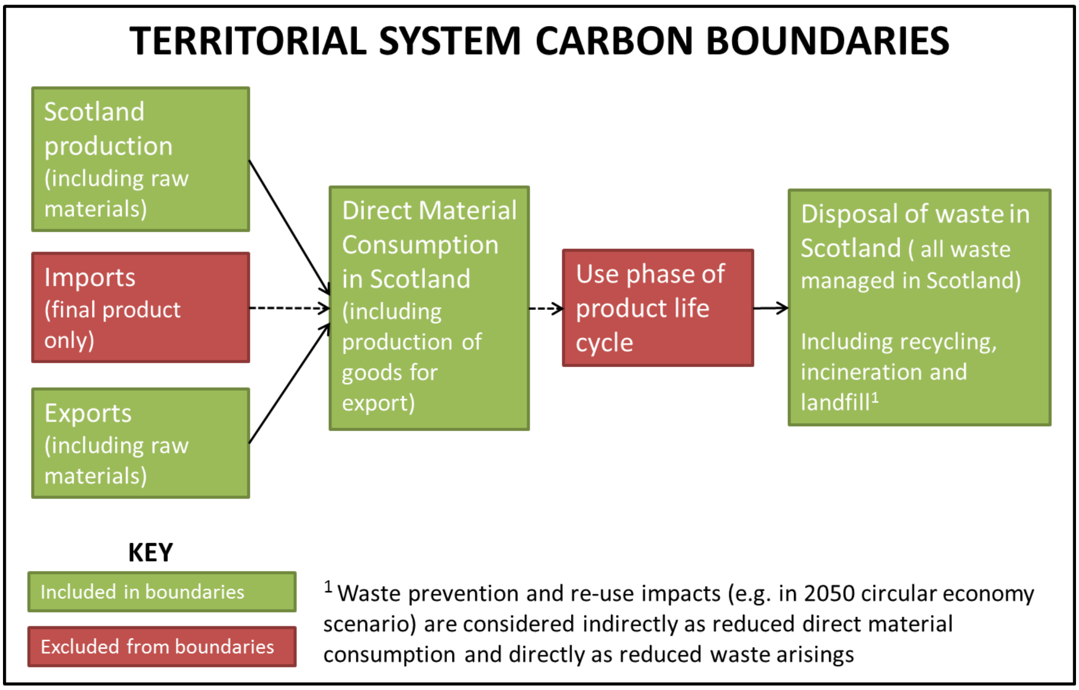


Diagram 3.2 The system boundaries of Scotland's material and waste flows using *territorial* carbon accounting boundaries



3.2 2050 Scenarios

The 2012 baseline was built on to create four scenarios describing the tonnage and carbon impacts of material consumption in Scotland in 2050. These four scenarios reflect different levels of material production and consumption, as shown in the matrix below; they are not economic forecasts, but rather hypothetical scenarios designed to highlight the opportunity for carbon savings in a more circular economy. In the business as usual scenario, production and consumption are assumed to remain at high levels, continuing on from current trends[12]. In the resource efficiency scenario, producers, retailers and other businesses reduce production impacts (perhaps due to rising resource prices) but consumers do not change their behaviours. The resource efficiency scenario is considered different to the circular economy scenario in that new approaches to reduce waste and energy inefficiencies are adopted but there is no wider change towards circular economy approaches such as long-life product design, remanufacturing and reuse which may reduce net material consumption as well. In the Limited Growth scenario, businesses fail to adapt their resource use meaning production impacts remain high but consumption is limited by poor economic growth. While the Limited Growth scenario is both unlikely and extremely undesirable, it has been included in this study in order to highlight the correlation between economic growth and emissions that is typical of a linear economy, and thus underscores the benefits of a circular economy in which economic growth and emissions reductions are simultaneously attainable. Finally, in the circular economy scenario, it is assumed that both businesses and consumers adapt to a low material impact society.

Diagram 3.3 A matrix of the material production and consumption levels considered in the four 2050 scenarios in the model

		Material and energy production impacts	
		HIGH	LOW
Consumption impacts	HIGH	Business as usual scenario	Resource Efficiency scenario
	LOW	Limited growth scenario	Circular economy scenario

Each of the 2050 scenarios are articulated via adjustments to five key drivers, described in Table 3.1. The WRAP (2010) study "Securing the Future" was used as a basis for future growth and imports assumptions[13]. Decarbonisation and waste assumptions were based on meeting Scottish and UK climate change and waste policies.

[12] This BAU scenario is distinct from that used in the Scottish Government's *Low Carbon Scotland: Meeting the Emissions Reduction Targets 2013-2027* (RPP2) as it incorporates Scotland's current grid decarbonisation commitment.
[13] WRAP (2010) Securing the Future: the role of resource efficiency.

Table 3.1 Drivers applied to the 2050 scenarios

Driver	BAU 2050 impact	Resource efficiency 2050 impact	Limited growth 2050 impact	Circular economy 2050 impact
Economic growth and impact on material consumption	Economic growth of 2.2%. Material consumption grows in line with this at 2.2%	Economic growth of 2.0%. Material consumption is reduced 25% (lack of adaption to material scarcity issues reduces growth rates slightly). Material use by business is reduced but demand remains high.	Economic growth of 0.2%. Material consumption is reduced 50% (lack of adaption to increasingly costly and global demands on resources reduces growth substantially)	Economic growth of 2.2%. Material consumption is reduced 50% (businesses reduce material impact of products and consumer demand for materials fall without impacting economic activity).
Proportion of materials imported	As WRAP (2010) study[14] (slight increase in most imports).	As WRAP (2010) study (slight increase in most imports).	Large increase in proportion of imports compared to 2012 (double WRAP analysis estimates) as economy relies on external activity due to limited growth domestically.	Substantial reduction in imports compared with BAU (half WRAP estimates), offset by partial increase in remanufacturing, increased product longevity and leasing models.
Decarbonisation of grid and transport	Domestic production and export carbon factors change in line with projections from UK Committee on Climate Change[15]. Imports remain unchanged.			
Waste management	In line with SSR[16] and ZW Regulations[17] (arisings reduced by 15% by 2017 and 70/25/5 mgmt. split).	In line with ZW Plan and SSR.	Arisings reduced by 65% (to reflect fall in consumption) and 70/25/5 mgmt. split.	Arisings reduced by 65% and 75/20/5 mgmt. split.
Proportion of recyclate exported	Same as 2012.	Same as 2012.	Same as 2012.	Substantially reduced for key materials.

[14] WRAP (2010) Securing the Future: the role of resource efficiency
http://www.wrap.org.uk/sites/files/wrap/Securing%20the%20future%20The%20role%20of%20resource%20efficiency.pdf
[15] Committee on Climate Change (2010) The Fourth Carbon Budget – reducing emissions through the 2020s
http://www.theccc.org.uk/publication/the-fourth-carbon-budget-reducing-emissions-through-the-2020s-2/
[16] Scottish Government (2013) Safeguarding Scotland's Resources
http://www.scotland.gov.uk/Publications/2013/10/6262/downloads
[17] Scottish Government (2012) The Waste (Scotland) Regulations
http://www.legislation.gov.uk/sdsi/2012/9780111016657/contents

4 Results

4.1 Headline results for 2012

Tables 4.1 and 4.2 below shows the *territorial* and *consumption* carbon impacts of material flows in Scotland in 2012. Table 4.3 shows the carbon impacts by material type.

The results show that Scotland's direct material consumption (DMC) was about 60Mt in 2012 (11.4 t per person). Waste impacts are about 19% of DMC. The *territorial* carbon impacts of Scotland's material use are substantially lower than the *consumption* carbon impacts. This is due to the large proportion of material imported to Scotland for consumption. Waste management has a net impact when *territorial* boundaries are considered but a net saving when *consumption* impacts are considered. This is because a large proportion of Scotland's waste is exported for recycling.

The material type analysis shows that, by weight, the three highest consumed material types are minerals (including fossil fuels), construction and food. By *territorial* carbon impact, the three material types with the highest carbon impact are food, minerals and non-ferrous metals. By consumption carbon impact, the three material types with the greatest impact are food, minerals and ferrous metals.

Table 4.1 The weight and (*territorial* and *consumption*) carbon impacts of material flows in Scotland in 2012 (whole nation results)

Indicator	Impact	Unit
Total direct material consumption	60,436,728	Tonnes
Total waste arisings	11,706,421	Tonnes
Territorial carbon impact of total material use	35,455,707	tCo2eq
Territorial carbon impact of waste	285,940	tCo2eq
Total *territorial* carbon impact	**35,741,646**	**tCo2eq**
Consumption carbon impact of Direct Material Consumption	57,717,771	tCo2eq
Consumption carbon impact of waste	-1,028,215	tCo2eq
Total *consumption* carbon impact of Direct Material Consumption	**56,689,556**	**tCo2eq**

Table 4.2 The weight and (*territorial* and *consumption*) carbon impacts of material flows in Scotland in 2012 (per capita results)

Material consumption per capita	Impact	Unit
Tonnages consumed	11.40	Tonnes
Waste management footprint	2.21	Tonnes
Territorial carbon impact	6.74	tCo2eq
Consumption carbon impact	10.70	tCo2eq

Table 4.3 The weight and (*territorial* and *consumption*) carbon impacts of material flows in Scotland in 2012 by material type

Material type	Direct Material Consumption (t)	*Territorial* carbon impact of material consumption (tCO2eq)	*Consumption* carbon impact of material consumption (tCO2eq)
Chemical and industrial materials	864,008	676,384	1,145,324
Construction material	14,919,057	1,050,858	1,052,784
Ferrous metal	1,564,815	90,120	4,832,905
Food and plants	6,893,165	19,078,100	27,071,648
Glass	310,272	262,481	278,607
Healthcare equipment	43,479	48,622	77,031
Household goods	294,947	110,524	886,271
Machinery	260,952	40,096	469,191
Minerals	31,939,875	6,343,909	8,444,443
Mixed metals	158,797	460,890	573,926
Non-ferrous metal	335,933	3,905,041	4,359,157
Paper	806,483	349,563	729,267
Plastics	386,895	461,604	1,273,328
Rubber	53,180	77,093	182,786
Textiles	189,510	912,780	4,030,132
Vehicles	518,342	1,271,905	1,772,432
Wood	897,019	315,736	538,539
Total	**60,436,729**	**35,455,708**	**57,717,771**

4.2 Scenario analysis for 2050

Tables 4.4, 4.5 and 4.6 and Graphs 4.1 and 4.2 below show the weight and (*territorial* and *consumption*) carbon impacts for the 2012 baseline and all 2050 scenarios. The results show that direct material consumption impacts varies significantly depending on the different assumptions around economic growth, material production and consumption, and changing import/export ratios.

In the business as usual scenario, material consumption increases while waste arisings decrease relative to the 2012 baseline. *Territorial* carbon impacts under BAU also decrease relative to the baseline while *consumption* carbon impacts increase significantly. Similarly in the resource efficiency scenario, material consumption increases and waste arisings decrease, however both *territorial* and *consumption* carbon impacts are reduced relative to the 2012 baseline.

Table 4.4 Weight and (*territorial* and *consumption*) carbon impacts for the 2012 baseline and all 2050 scenarios (whole nation results)

Indicator	Unit	2012 impact	BAU 2050 impact	Resource efficiency 2050 impact	Limited growth 2050 impact	Circular economy 2050 impact
Total material consumption	Tonnes	60,436,728	138,176,754	96,198,597	32,602,009	69,088,377
Total waste arisings	Tonnes	11,706,421	9,950,458	9,950,458	4,097,247	4,097,247
Territorial carbon impact of total material use	tCo2eq	35,455,707	26,137,042	18,196,598	4,277,176	15,087,556
Territorial carbon impact of waste	tCo2eq	285,940	-471,010	-471,010	-193,909	-386,020
Total *territorial* carbon impact	**tCo2eq**	**35,741,646**	**25,666,032**	**17,725,587**	**4,083,267**	**14,701,537**
Consumption carbon impact of DMC	tCo2eq	57,717,771	114,644,251	79,815,278	27,897,207	56,449,521
Consumption carbon impact of waste	tCo2eq	-1,028,215	-1,439,824	-1,439,824	-591,557	-949,034
Total *consumption* carbon impact of DMC	**tCo2eq**	**56,689,556**	**113,204,427**	**78,375,454**	**27,305,650**	**55,500,488**
Difference between *consumption* and *territorial* results	%	37%	77%	77%	85%	74%

Table 4.5 Weight and (*territorial* and *consumption*) carbon impacts for all 2050 scenarios (as a proportion of the 2012 baseline)

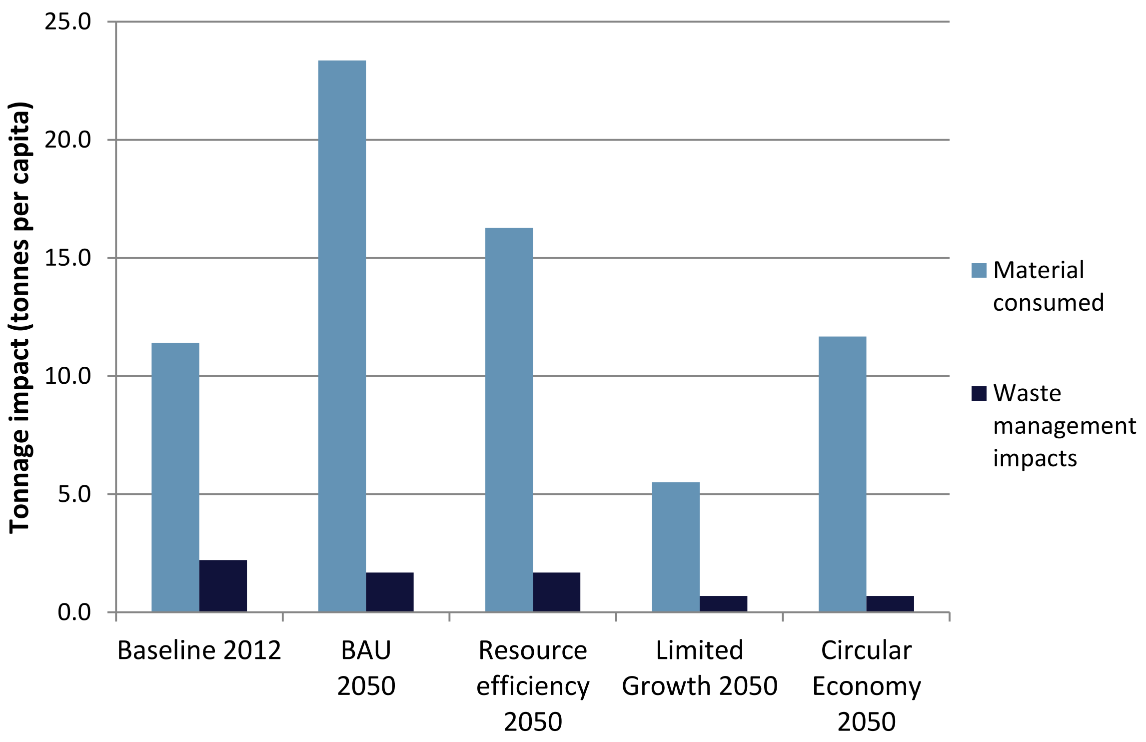
Total material consumption	BAU 2050 impact	Resource efficiency 2050 impact	Limited growth 2050 impact	Circular economy 2050 impact
Total material consumption	129%	59%	-46%	14%
Total waste arisings	-15%	-15%	-65%	-65%
Territorial carbon impact of total material use	-26%	-49%	-88%	-57%
Territorial carbon impact of waste	-265%	-265%	-168%	-235%
Total *territorial* carbon impact	**-28%**	**-50%**	**-89%**	**-59%**
Consumption carbon impact of Direct Material Consumption	99%	38%	-52%	-2%
Consumption carbon impact of waste	40%	40%	-42%	-8%

Total *consumption* carbon impact of Direct Material Consumption	**100%**	**38%**	**-52%**	**-2.1%**

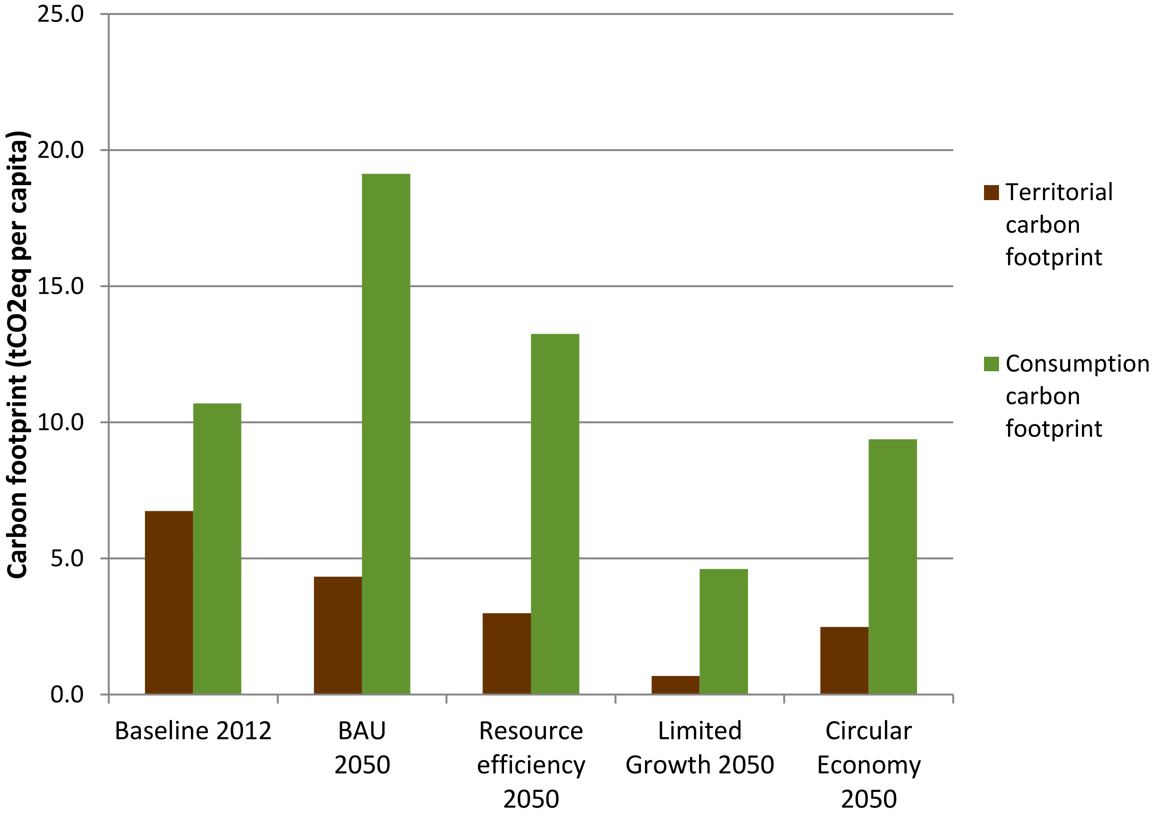
Table 4.6 Weight and (*territorial* and *consumption*) carbon impacts for the 2012 baseline and all 2050 scenarios (per capita results)

Material consumption per capita	**Unit**	**Baseline 2012**	**BAU 2050 impact**	**Resource efficiency 2050 impact**	**Limited growth 2050 impact**	**Circular economy 2050 impact**
Material consumed	Tonnes per person	11.4	23.4	16.3	5.5	11.7
Waste management impacts	Tonnes per person	2.2	1.7	1.7	0.7	0.7
Territorial carbon footprint	tCo2eq per person	6.7	4.3	3.0	0.7	2.5
Consumption carbon footprint	tCo2eq per person	10.7	19.1	13.2	4.6	9.4

Graph 4.1 The (consumption and waste) material flows impacts for the 2012 baseline and all 2050 scenarios (tonnes per capita)



Graph 4.2 *Territorial* and *consumption* carbon impacts for the 2012 baseline and all 2050 scenarios (tonnes per capita)



5 Data Quality and Sensitivity Analysis

5.1 Approach to data quality and sensitivity analysis

The data available for material flow analysis in Scotland is currently extremely limited, requiring this project to use uncertain sources and create assumptions where data gaps existed. A data quality assessment and sensitivity analysis was conducted as part of this project to understand the impact of this on the results. This analysis focused on two areas:

- Are changes to the most sensitive and uncertain data likely to change the conclusions?
- Are changes to the most significant assumptions likely to change the conclusions?

All the main datasets were assessed using a qualitative data quality indicator, which was developed for use on the Scottish Carbon Metric and includes consideration of the geographic, technical and time relevance of the data (more details of this approach can be found in the technical report for the Carbon Metric)[18]. The data quality analysis revealed that the poorest quality datasets were the

[18] ZWS (2012). The Scottish Carbon Metric: A national carbon indicator for waste (Technical Report). http://www.zerowastescotland.org.uk/sites/files/zws/2011%20Carbon%20Metric%20-%20Technical%20Report%20published%202013.pdf

domestic production tonnage estimates and the carbon factors for production. The full data quality assessment tables for these datasets are shown in Annex 2.

The sensitivity analysis varied some of the main assumptions and considered how these changed the results, including:

- Whether the material flows tonnages were comparable to material flow accounts dataset published annually by ONS, scaled by Scottish population levels;
- Whether increasing or decreasing the domestic production tonnages had a significant effect on the overall results;
- Whether the *territorial* and *consumption* results were comparable to the Scottish Government's published carbon accounts;
- Whether changing carbon factors for key material types had a significant impact on the results;
- Whether the assumption that a 2050 Circular Economy scenario could cut material consumption in Scotland by 50% had a significant impact on the results.
- Whether changes in assumptions of economic growth had a significant impact on the results.

5.2 Conclusions of data quality and sensitivity analysis

The most uncertain datasets were the material flows and carbon factors for domestic production in Scotland. Whilst the material specific flows differ from the ONS material flow accounts (an alternative source for this information), the total tonnage figures are very similar. This suggests that caution should be used when interpreting material specific results about domestic production but changes are unlikely to affect the overall scale of the results.

The results of the sensitivity analysis show that most data changes do not change the conclusions. The model was most sensitive to changes in material production tonnages (both in the 2012 baseline and 2050 Circular Economy scenario). See Annex 2 for full sensitivity analysis table for the 2050 Circular Economy scenario assumption that material consumption would fall by 50% compared to 2012 levels. Changes to these data and assumptions would change the scale of the results but would not reverse the direction of change.

Long term projections of economic growth for Scotland vary between 1-3% for different sources. The latest Scottish Government report from August 2014 suggests growth may be 2.5%, noting the average independent forecast for Scotland GDP growth in 2014 is also 2.5%[19]. The most recent estimate from the Organisation for Economic Co-operation and Development (OECD) suggested long term growth rates for the UK of 2.5%[20]. The assumption of long term growth rates used in this study of 2.2% is probably slightly conservative but considered appropriate, given the project is forecasting much further into the future than most studies.

Four key uncertainties which cannot be tested due to lack of data are:

- **The scale of raw material imports:** All import tonnages are given for the final product, rather than the raw materials used to produce them. This is a common assumption in material flow analysis but can be very significant as many material intensive products are produced outside of Europe. A 2014 European study by CREEA[21] which attempted to quantify raw material equivalents for EU countries suggests that total material requirements may be much higher than reported. The study assessed the UK material footprint including raw material tonnages for imports put material use at twice the level estimated in this analysis (117Mt when scaled to Scotland by population).

[19] Scottish Government (August 2014) State of the Economy http://www.scotland.gov.uk/Resource/0045/00457345.pdf

[20] OECD (2014) OECD Economic Outlook for the G20 http://www.oecd.org/eco/outlook/G20-economic-projections-handout.pdf

[21] CREEA (2014) The global resource footprint of nations: carbon, water, land and materials embodied in trade and final consumption http://creea.eu/index.php/7-project/8-creea-booklet

- **Intra-UK trade:** Trade between UK nations is not currently assessed but is likely to have a significant impact on material flows in Scotland. This would require the development of an economic or material flows model which included trade data from all four nations.

- **Impacts of Grid Decarbonisation on Fossil Fuel Consumption:** Scotland's commitment to decarbonise the national electricity grid could result in decreasing demand for fossil fuels. This in turn could reduce fossil fuel material flows and associated emissions in all four 2050 scenarios.

- **Impacts of Increased Remanufacturing and Repair on Energy Use:** Reducing material consumption through a more circular economy will require more remanufacturing and repair activities. This in turn could result in greater electricity use by this sector, affecting emissions.

Further research is required to improve understanding of these areas and of material flows in Scotland in general. Expert advisors for the project suggested that material flow analysis linked to input-output tables could be especially useful in creating a more complete and detailed picture of Scotland's material flows.

6 Conclusions

This project has developed and analysed the carbon impacts of material flows in Scotland. It considers the domestic (*territorial*) and global (*consumption*) carbon impacts of material consumption in Scotland in 2012 and the carbon impacts of four scenarios for 2050 in which the production and consumption of materials vary. The results show that Scotland consumed about 60.4Mt of material in 2012, which is the equivalent to 11.4t of material per person per year. 44% (26Mt) of this material was imported and over 11.7Mt was waste, the equivalent to 2.2t of waste per person.

This report provides an initial but significant first look at the carbon savings possible through a more circular Scottish economy which future research can build upon in several ways. First, the practical obstacles and opportunities involved in transitioning towards a circular economy should be explored in detail, with particular focus on identifying the material types and sectors which offer the greatest potential carbon savings through improved circularity. Second, Scotland's material consumption accounts should be compared with those of other EU member states to determine whether relative differences (as seen in Table 6.1) are the result of methodological variations in accounting or real-world circumstances which could help inform Scottish policy. Finally, Scotland's material consumption accounting should incorporate raw materials from imports as these can have a significant impact on a country's overall material consumption figures (see Table 6.1)

Table 6.1 Resource productivity and material consumption per capita by nation

Country	Resource productivity (excludes raw material consumption of imports) 2012, Eurostat[22] (t per capita)	Material consumption (includes raw material consumption of imports) 2007, CREEA (t per capita)
Scotland	11.4 (this study)	-
UK	9.3	23.2
France	11.9	21.2
Ireland	24.2	58.9
Netherlands	10.5	25.6

[22] Eurostat (2014) Resource productivity http://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Res_Prod_GDP_and_DMC_by_countries_2012.png&oldid=192367

EU-27	13.5	21.2
World average	-	9.9

The carbon impacts of our material consumption in Scotland are substantial. Table 6.2 shows that material consumption is responsible for the majority of Scotland's carbon emissions, regardless of whether *territorial* or *consumption* boundaries are used. This is a new way of considering our carbon impacts and highlights the opportunity for Scotland to reduce both its domestic (*territorial)* and global (*consumption)* carbon footprints through a more circular Scottish economy.

Table 6.2 *Territorial* and *consumption* carbon impacts for Scotland

Carbon accounting boundary	Material carbon footprint (2012)	Total carbon footprint	Material carbon footprint as a proportion of total[23]
Territorial carbon footprint	36 MtCO2eq (6.7 tCO2eq/capita)	53 MtCO2eq (2012)[24]	68%
Consumption carbon footprint	57 MtCO2eq (10.7 tCO2eq/capita)	77 MtCO2eq (2012)[25]	74%

The materials which contribute most to Scotland's carbon footprint vary depending on the carbon accounting approach taken as well (see Table 6.3 below). This suggests that policy makers should focus on different material types depending on how they want to maximise their impact (e.g. reducing Scotland tonnage material consumption versus reducing Scotland's global environmental impact).

Table 6.3 Top 5 Scottish material flows in 2012 by weight, *territorial* carbon impact and *consumption* carbon impact

Significance	Tonnage	*Territorial* carbon impact	*Consumption* carbon impact
1	Minerals	Food and plants	Food and plants
2	Construction material	Minerals	Minerals
3	Food and plants	Non-ferrous metal	Ferrous metal
4	Ferrous metal	Vehicles	Non-ferrous metal
5	Wood	Construction material	Textiles

The 2050 scenario analysis shows that a circular economy scenario could save carbon emissions compared to the business as usual scenario, in both *territorial* and *consumption* terms. The *territorial* carbon savings of the circular economy scenario compared to the BAU scenario (11MtCO2eq) illustrates how circular economy strategies can assist Scotland in achieving its ambitious emissions

[23] This calculation should be treated with caution as it combines data from multiple datasets with different boundaries. It should be used as an indication of scale, rather than an accurate estimate.
[24] Scottish Government (2014). Scottish Greenhouse Gas Emissions 2012. http://www.gov.scot/Resource/0045/00452084.pdf
[25] Scottish Government (2015). Scotland's Carbon Footprint 1998-2012. http://www.gov.scot/Resource/0047/00472991.pdf

reduction targets[26]. Whilst the Limited Growth scenario shows emissions may be reduced further than even the circular economy scenario, the economic and social implications of sustained low-growth make it extremely undesirable as an outcome.

In *consumption* terms, the Circular Economy scenario offers substantial carbon savings (57.7 MtCO2eq) compared to the BAU 2050 scenario and has a similar carbon impact to the 2012 baseline despite an annual economic growth rate of 2.2% annually up to 2050. The *territorial* impacts of the circular economy scenario are also lower than 2012 levels. This indicates it is possible to save carbon emissions in Scotland even if economic activity is increased, as long as that economic activity also achieves material savings, such as those offered through the circular economy.

Policy makers concerned about the environmental impacts of Scotland's material consumption should use both *consumption* and *territorial* carbon impacts to support their decision making. The results of this project show that a more circular Scottish economy could provide substantial carbon savings, both in *territorial* and *consumption* terms, without compromising economic growth.

[26] The Climate Change (Scotland) Act 2009 sets targets to reduce Scotland's emissions of greenhouse gases by at least 42% by 2020 and 80% by 2050 compared to the 1990/95 baseline.

Annex 1 Detailed Methodology

This methodology refers to the key documents and datasets created to model this project.

Material consumption tonnage data

1. UK Exports and Imports data is estimates from HMRC data for material flow by HS2 codes[27] (for mapping of codes to analysis material definitions, see main model tab "HS2 codes") and scaled to Scottish level using a population estimate for 2012. There is no existing data on intra-UK trade, therefore, this has been ignored in the model. This simplification is likely to have a significant impact on the results.

2. Domestic production data is gathered from various sources including Prodcom[28], WRAP models[29], Eurostat[30] and ONS[31] and scaled to Scotland. Details are given in table 5 of the "Materials" tab of the main model.

Healthcare domestic production is estimated based on data from an external report which includes monetary estimates of the size of the UK domestic medical device market and exports and imports in 2003 (see Table 5a. of the "Materials" tab)[32].

3. Exports are subtracted from domestic production to give an intermediate estimate of direct consumption figures (see Table 2, "2012 Baseline" tab). Imports are added to domestic consumption figures to give direct material consumption figures for Scotland for 2012 by 17 material type categories.

Steel (included in the "ferrous metals" category in the model) consumption reflects the strong reliance on imported raw materials in Scotland. Domestic production is assumed to be zero, exports are extrapolated from HMRC UK data. Domestic consumption is extrapolated from WRAP assumptions for the Courtauld Commitment that, in the UK 74% of steel (as there is no domestic production of steel). These calculations are shown in Table 5b. in the materials tab.

Fossil fuels, as a material type, are considered as part of "other minerals", which includes all minerals except those used in construction and demolition. The 2012 ONS UK data suggests that fossil fuels make up 61% of this category (see Materials tab, Table 9). The carbon factors have been altered from the original carbon metric factors for production of this material category to reflect this significant difference in material composition. The waste management carbon factors have not been altered from the default factors, as published in the Scottish Carbon Metric for "other minerals", because it is assumed that fossil fuels are not wasted but burnt for fuel.

Note: Domestic consumption figures are sometimes minus numbers (where exports exceed domestic production). This is possible because exports may rely on imports for intermediate production. Although these domestic consumption is calculated as an intermediate step to

Waste data

1. The analysis is based on the 2012 waste arisings dataset of all Scottish waste, as supplied by SEPA. The household and similar waste management is split by material type using composition

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[27] HMRC (2014) Build your own data tables by commodity code https://www.uktradeinfo.com/Pages/Home.aspx

[28] http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/introduction

[29] Including WRAP Courtauld model and WRAP (2012) WEEE model, WRAP (2012) Furniture Flows model and WRAP (2014) UK food flows

[30] Eurostat material flow accounts 2012 http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Material_flow_accounts

[31] ONS (2014) http://www.ons.gov.uk/ons/taxonomy/index.html?nscl=Environmental+Accounts

[32] PRIME Faraday Technology Watch (2003) Medical Devices the UK industry and its technology development (source: Espicom), table 5, page 6 and table 7 page 8

analysis estimates from ZWS, as used and peer reviewed in the Scottish Carbon Metric (documented in the Technical Report published on the ZWS website in 2013). The "Household and similar waste" total arisings was split into material types using ZWS (2010) waste composition analysis data[33], as detailed in the Carbon Metric Technical Report.

2. Proportion of waste managed inside and outside of Scotland is estimated using SEPA waste data tables for 2011[34], Tables 9, 13 and 16 (latest available data). In theory, non-Scottish waste managed in Scotland should be excluded from consumption boundary calculations and included in *territorial* boundary calculations. However, the difference between these datasets is only 34t of material sent to landfill, therefore it was decided to use the consumption boundaries for all waste managed inside/outside Scotland as applying *territorial* boundaries would overcomplicate the model. The average distance travelled was estimated internally by ZWS experts and applied to the carbon factors for waste.

Note: Waste imported to Scotland for management is not considered. This would only affect the *territorial* carbon impacts and, after investigation, it was found this would have a less than 0.1% impact on the overall results. Therefore, it was excluded for simplicity, as is common practice in LCA.

In the 2050 scenarios, there is an assumption that the composition of waste does not change compared to 2012 composition. It is likely that waste composition will change (as it has always changed in line with new consumption patterns) but it is difficult to predict what waste streams will increase or decrease relative to today's composition.

Carbon data

The carbon emission factors were calculated in a separate spreadsheet called "Carbon Factors" and copied and passed over to the main model once completed.

1. The Scottish Carbon Metric is used as a basis for the carbon emission factors for this analysis. The 2012 carbon factors, as published on the ZWS website in 2014[35], were adapted in several ways:

- Production carbon factors were created based on the production data for materials and the material categories used in the main model based on HMRC HS2 commodity codes[36]. (see Table 1, "Production CF" tab)
- Imported products have been assumed to have the same process carbon emissions factors as UK products but transport emissions have been modified to reflect the country of origin. This is an over-simplification for some materials, for example, metals which require large energy inputs and are often manufactured in countries with very different, often more energy intensive, electricity systems.
- The transport assumptions for waste exported for recycling was updated to reflect internal analysis by ZWS experts (see Table 2 and 4, "General assumptions" Tab).
- The carbon emission factors were split into two classifications based on system boundaries: one for *territorial* boundaries and one for consumption boundaries. Factors were developed for material produced and waste managed inside and outside of Scotland. For each set of factors the carbon impact of waste by material type for production, recycling, incineration and landfill of waste was calculated to give a CO2eq per tonne of material carbon factor. The diagram below gives details on these boundaries.

Consumption boundaries

[33] ZWS (2010) The Composition of Municipal solid waste in Scotland http://www.zerowastescotland.org.uk/sites/files/zws/Scotland_MSW_report_final.pdf
[34] SEPA (2013) Scottish Waste Data Tables for 2011 http://www.sepa.org.uk/waste/waste_data.aspx
[35] ZWS (2014) Scottish Carbon Metric Technical Report http://www.zerowastescotland.org.uk/content/carbon-metric-technical-report-2013-0
[36] HMRC https://www.uktradeinfo.com/CodesAndGuides/GoodClassificationSystems/Pages/AboutHS.aspx

Activity occurs in Scotland				Activity occurs in UK/Global			
Production	**Recycling**	**Incineration**	**Landfill**	**Production**	**Recycling**	**Incineration**	**Landfill**
production (domestic transport assumptions) Excludes filling and use phase	transport (domestic assumptions), reprocessing, avoided production NB: avoided landfill not included as landfill impacts are shown separately.	transport (Scottish assumptions), process	transport (Scottish assumptions), process	production (UK/global transport assumptions) Excludes filling and use phase	transport (UK/global assumptions), reprocessing, avoided prod, avoided LF NB: avoided landfill not included as landfill impacts are shown separately.	transport (UK assumptions), process	transport (UK assumptions), process

***Territorial* boundaries**							
Activity occurs in Scotland				**Activity occurs in UK/Global**			
Production	**Recycling**	**Incineration**	**Landfill**	**Production**	**Recycling**	**Incineration**	**Landfill**
production (domestic transport assumptions) Excludes filling and use phase	transport (domestic assumptions), reprocessing NB: avoided landfill not included as landfill impacts are shown separately.	transport (Scottish assumptions), process	transport (Scottish assumptions), process	Distribution and retailer transport only	transport (to non-Scottish UK, EU or International border only)	transport (to non-Scottish UK border only)	transport (to non-Scottish UK border only)

At this stage the carbon emission factors were copied into the main model. The carbon emission factors are combined with the materials and waste data in the “2012 baseline” tab.

2. For the *territorial* carbon emission factors, all emissions associated with production and waste management that occurs in Scotland are included (whether the products are used in Scotland or exported). Any transport emissions associated with production and waste management that occurs in Scotland for goods which have been made and waste managed outside of Scotland are also included. This is shown in Table 6 and 7, “2012 Baseline” tab. The tonnages of domestic production and imports are multiplied by their carbon factors and summed to give direct material consumption *territorial* carbon impacts.

The waste tonnages and carbon emission factors are combined for recycled, incinerated and landfilled waste for each material type (Table 7). Waste exported is assumed to be recycled (for *territorial* model the only emissions considered for waste exported are the emissions associated with transporting the waste out of Scotland).

3. The consumption carbon emission factors include the emissions associated with the production and waste management of any goods consumed in Scotland (domestically produced goods which are not exported and imports). All emissions associated with exports are excluded. In Table 10, the proportion

of direct material consumption from imports is calculated based on the tonnage data in Table 2, "2012 Baseline" tab. This proportion is multiplied by the imports carbon emission factors from Table 8. The remaining tonnages are multiplied by the domestic production carbon emission factors. This methodology assumes that all imports are used for domestic consumption, which is not consistent with the assumptions in table 2 (that exports can be based on imported materials). However, there is no data available which could be used to improve this simplified approach.

The waste tonnages and carbon emission factors are combined for recycled, incinerated and landfilled waste for each material type (Table 11). Waste exported is assumed to be recycled.

Note: The production impacts of materials and products produced outside of the UK are poorly understood, as are the impacts of some overseas recycling processes. Where possible the most appropriate geographical data has been used but often the factors for the UK analysis have been used as a substitute where no geographically specific data exists. This is a limitation of the analysis, however, most of the carbon emissions data draws on European and global averages (for many materials, this is the only suitable data available). Therefore, whilst there will be inaccuracies and uncertainties, the risk of misinterpreting the impacts of imports is reduced. In the future, more country specific carbon data could be developed using input-output analysis.

Headline results

The results from Tables 2-11 were presented as headline national data for Scotland and broken down by per person estimates using population data for Scotland (Tables 1 and 1a.). These results were compared to Scottish Government estimates of *territorial* and consumption carbon impact[37] to ensure the figures were within a realistic range. Further sensitivity analysis was also conducted.

2050 scenarios

The 2012 baseline scenario was developed further to estimate the change in tonnage and (*territorial* and consumption) carbon impact by 2050 which could then be compared to each other and the original 2012 baseline.

Assumptions about the key drivers of material impacts and consumption were developed using four scenarios, as illustrated below. For each scenario, the drivers were altered to reflect the scenario. For example, the Business As Usual (BAU) scenario was based on a continuation of the current trend for high material and energy production impacts and high consumption impacts. The scenario assumed that material consumption continued to grow in line with economic growth of 2.2% (this is based on the WRAP (2010) Securing the Future study[38] growth assumption. It is acknowledged that future growth rate assumptions made in the early 21st century are likely to be lower than those assumed in the late 20th century, when the WRAP study was conducted. However, on expert economic advice it was decided not to change this assumption).Whereas, in the Circular Economy scenario, material consumption was assumed to decouple from economic growth (still assumed to be 2.2%) due to a changes in production and consumption patterns (see Diagram 3.3 in the main report).

Table 3.1 in the main report summarises the main drivers for each of the 2050 scenarios. These are described in more detail in the text below.

[37] Scottish Government (2013) http://www.scotland.gov.uk/Publications/2013/09/5719/downloads and Scottish Government (2014) http://www.scotland.gov.uk/Publications/2014/06/5527/downloads
[38] WRAP (2010) Securing the Future: the role of resource efficiency http://www.wrap.org.uk/sites/files/wrap/Securing%20the%20future%20The%20role%20of%20resource%20efficiency.pdf

2050 Business As Usual (BAU) Scenario

The BAU scenario is an extrapolation of existing policies and targets, rather than a “do nothing” scenario. Some of the expected changes e.g. decarbonisation of the UK electricity and transport grids are likely to have significant impacts on the results but are not certain to occur.

Driver: Economic growth of 2.2% leads to material consumption growth of 2.2%

1. The projection of annual Scottish direct material consumption by 2050 (see Table 2, “2050 BAU” tab) was estimated using the compound interest formula:

New Value = Present Value *(1 + growth rate) ^ years

Material consumption growth rate is assumed to be 2.2%, in line with economic growth projection for this scenario. The 2.2% assumption is based on the WRAP (2010) Securing the Future study growth rate assumption and verified by the ZWS economist. An underlying assumption is that this level of material consumption is physically possible – as we are already reaching planetary limits for some of our material use, this assumption is unlikely to be realistic. This point should be considered when interpreting the results.

Driver: Proportion of materials imported increases slightly for most materials in line with WRAP (2010) estimates

1. The proportion of imports of total material consumption was estimated using data from WRAP (2010) Securing the Future study. The data from this study was used to give the change in proportion of imports for key materials from 2010 to 2020. This was then projected to 2050, assuming no further change in trend. As the absolute tonnages of imports and domestic projection are different in this study to the main analysis, the relative change is used to estimate the proportion of imports in 2050 (see Tables 6 and 7, “Materials” tab).

Mixed metals are estimated from a weighted average of metals (using the carbon metric estimates of proportions of metal types) and food projected imports are estimated from DEFRA food statistics Pocket book[39] estimates of the increase in the proportion of imported food to the UK from 1992 to 2012. For some materials, no projections of future imports were found so these were kept constant at 2012 levels for all scenarios. These materials were glass, textiles, machines and electrical products, vehicles and household products, which together make up 7% of the import tonnages for Scotland in 2012.

2. The domestic consumption of materials was estimated by subtracting the imports from the total material consumption estimates (see Table 2, “2050 BAU” tab).

3. The domestic production was estimated by dividing the domestic consumption tonnages by the proportion of domestic production to exports in 2012 (see Table 2, “2050 BAU” tab).

4. The exports data is estimated by subtracting the domestic production from domestic consumption (see Table 2, “2050 BAU” tab).

Driver: Decarbonisation of the grid and transport reduces the carbon factors for all materials

1. The carbon factors are modified based on estimates of energy and transport decarbonisation projections for 2050, as calculated by the UK Committee on Climate Change[40]. The carbon intensity of

[39] DEFRA (2014) Food Stats Pocket Book https://www.gov.uk/government/collections/food-statistics-pocketbook

[40] Climate Change Committee (2010) The Fourth Carbon Budget – reducing emissions through the 2020s http://www.theccc.org.uk/publication/the-fourth-carbon-budget-reducing-emissions-through-the-2020s-2/

electricity supply is assumed to fall from 496 gCO2 in 2010 to 12 gCO2 (98%) in 2050. The reduction in carbon intensity of transport is not calculated directly by the CCC but estimates for expected reductions for heavy goods vehicles to 2030 has been extrapolated to 2050 for this project. The model assumes the carbon intensity of transport to fall by 37% from 2010 to 2050.

2. The carbon factors used in the 2012 baseline have been modified to reflect the energy and transport decarbonisations projections described above. The carbon emissions factors for production and waste of each material type include emissions from materials, energy and transport. The diagrams below summarise how the carbon factors have been modified.

Consumption boundaries	
Activity occurs in Scotland	**Activity occurs in UK/Global**
Material impacts (2014 assumptions) + energy impacts (2050 assumptions) + transport impacts (2050 assumptions)	Material impacts (2014 assumptions) + energy impacts (2014 assumptions) + transport impacts (2014 assumptions)

***Territorial* boundaries**	
Activity occurs in Scotland	**Activity occurs in UK/Global**
Material impacts (2014 assumptions) + energy impacts (2050 assumptions) + transport impacts (2050 assumptions)	Transport which occurs within Scotland only (2050 assumptions)

3. For production carbon emission factors where the material and energy impacts were embedded in the data together, the following method was used to estimate the 2050 carbon emissions factor. This method estimates the energy requirements for producing 1t of material and converts this from 2014 to 2050 estimates using the assumptions about decarbonisation described above. It is acknowledged that this is a crude approach, but it is considered in line with the generally high level approach taken in this analysis.

a. An appropriate material equivalent was found in SimaPro[41] and the fossil fuel (coal, natural gas, crude oil) requirements for producing 1kg of material was recorded in kg (this sometimes required a conversion from a more common unit, such as cubic metres for natural gas).

b. This was then converted to carbon impact of fossil fuel use per t of material produced using SimaPro figures for fossil fuels (documented in the main spreadsheet, Materials tab, Tables 8 and 9).

c. The result was then reduced by 98% (to convert energy impacts from 2014 to 2050) and this figure was subtracted from the 2014 process carbon emissions factor (kgCO2eq per t) for the material.

d. Any general transport carbon emission assumptions made in for the 2014 figure were then modified to give the final 2050 carbon factor for a material.

e. The chosen SimaPro processes are saved in a project called “Carbon impacts of CE”. They were calculated using the IPCC2013 GWP100 method in version 8 of SimaPro.

[41] SimaPro, version 8.0.3.14 (2014) http://www.simapro.co.uk/

4. These 2050 factors have been applied to all the 2050 scenarios.

Driver: Waste management changes in line with SSR and ZW Regulations[42] (arisings reduced by 15% and 70/25/5 management split (recycling/incineration/landfill). The proportion of recyclate exported is assumed to remain the same as 2012.

1. The 2012 waste arisings data was reduced by 15% compared to 2012 figures for all material types in line with SSR Scottish Government policy[43] (see Table 3, "2050 BAU" tab).

2. Of the waste arising by material type, 25% of tonnages were assumed to be sent to incineration and 5% were assumed to be sent to landfill. The remain 70% are split between recyclate managed in Scotland and exported for reprocessing using the 2012 reprocessing export data. These assumptions are in line with Scottish Government policy (see Table 3, "2050 BAU" tab).

Driver: Proportion of recyclate exported

This is assumed to be equal to the 2012 export levels for the BAU scenario.

Supporting drivers are drivers which do not have a direct impact on the model as they are assumed to be linked to one or more of the main drivers or they are not significant to the analysis of this project. Supporting drivers include population change and changes in material costs. Both these supporting drivers are assumed to be linked to economic growth. Material costs are not considered in detail in this model.

Resource Efficiency scenario

Driver: Economic growth of 2.0%. Material consumption is reduced by 25% compared to BAU.

1. Scottish total material consumption was estimated using the compound interest formula:

New Value = (Present Value *(1 + growth rate) ^ years) - 25%

Material consumption growth rate is assumed to be 25% less than BAU scenario, which is in line with economic growth. The 2.0% assumption is based on the WRAP (2010) Securing the Future study growth rate assumption and then modified to account for the lack of adaption to material scarcity issues in this scenario which is assumed to reduce growth rates slightly compared to the BAU potential.

Driver: Proportion of materials imported increases slightly for most materials in line with WRAP (2010) estimates

1. The same methodology for the BAU scenario is applied to this scenario for this driver.

Driver: Decarbonisation of the grid and transport reduces the carbon factors for all materials

1. The same methodology for the BAU scenario is applied to this scenario for this driver.

[42] Scottish Government (2012) The Waste (Scotland) Regulations http://www.legislation.gov.uk/sdsi/2012/9780111016657/contents
[43] Scottish Government (2013) Safeguarding Scotland's Resources http://www.scotland.gov.uk/Publications/2013/10/6262/downloads

Driver: Waste management changes in line with SSR and ZW Regulations (arisings reduced by 15% and 70/25/5 management split (recycling/incineration/landfill). The proportion of recyclate exported is assumed to remain the same as 2012.

1. The same methodology for the BAU scenario is applied to this scenario for this driver.

Driver: Proportion of recyclate exported

1. The same methodology for the BAU scenario is applied to this scenario for this driver.

Limited growth scenario

Driver: Economic growth of 0.2%. Material consumption is reduced by 50% compared to BAU.

1. Scottish total material consumption was estimated using the compound interest formula:

New Value = (Present Value *(1 + growth rate) ^ years) - 50%

Material consumption growth rate is assumed to be 50% less than BAU scenario (see Table 2, “2050 Limited G” tab). The 0.2% economic growth assumption is based on the WRAP (2010) Securing the Future study growth rate assumption and then modified to account for the lack of adaption to material scarcity issues and increasing costs in material production in this scenario. The 50% reduction in material consumption reflects the changes consumers are forced to make in their consumption habits in such poor long term economic circumstances. This is assumed to reduce growth rates dramatically compared to the BAU potential as consumption falls.

Driver: Proportion of materials imported increases substantially for most materials in line with WRAP (2010) estimates

1. The proportion of imports was calculated as in the BAU and then doubled to reflect an increased reliance on production from abroad as domestic production is minimal. The WRAP 2010 study predicts that chemical (fertiliser) consumption will be increasingly based on domestic production. However, in order to keep the material trend in line with the general import assumption trends for this scenario, the proportion of chemicals imported is assumed to remain the same as the 2012 baseline (see Table 6, “Materials” tab).

Driver: Decarbonisation of the grid and transport reduces the carbon factors for all materials

1. The same methodology for the BAU scenario is applied to this scenario for this driver.

Driver: Waste management changes in line with SSR and ZW Regulations (arisings reduced by 65% and 70/25/5 management split (recycling/incineration/landfill). The proportion of recyclate exported is assumed to remain the same as 2012.

1. The same methodology for the BAU scenario is applied to this scenario for this driver, except arisings are reduced by 65% compared to 2012 figures for all material types, rather than 15%. 65% was chosen to reflect the 50% fall in material consumption, which is assumed to follow through to a similar fall in waste arisings, in addition to the 15% reduction expected in the BAU scenario. Waste management assumptions remain the same as BAU.

Driver: Proportion of recyclate exported

1. The same methodology for the BAU scenario is applied to this scenario for this driver.

Circular Economy Scenario

Driver: Economic growth of 2.2%. Material consumption is reduced by 50% compared to BAU.

1. Scottish total material consumption was estimated by 17 material types using the compound interest formula:

New Value = (Present Value *(1 + growth rate) ^ years) - 50%

Material consumption growth rate is assumed to be 50% less than BAU scenario, which is in line with economic growth. The 2.2% economic growth assumption is based on the WRAP (2010) Securing the Future study growth rate assumption. It is then assumed that material consumption has been cut by 50% due to the application of circular economy initiatives (see Table 2, “2050 CE” tab).

Driver: Proportion of materials imported decreases substantially for most materials in line with WRAP (2010) estimates

1. The proportion of imports was calculated as in the BAU and then halved. This reflects an important policy objective of the circular economy increase economic activity in Scotland and is in line with the net assumed reduction in consumption.

Driver: Decarbonisation of the grid and transport reduces the carbon factors for all materials

1. The same methodology for the BAU scenario is applied to this scenario for this driver.

Driver: Waste management changes are slight improved compared with BAU scenario and government policy (arisings reduced by 65% and 75/20/5 management split (recycling/incineration/landfill). The proportion of recyclate exported is assumed to remain the same as 2012.

1. The 2012 waste arisings data was reduced by 65% compared to 2012 figures for all material types as CE improvements are expected to have knock on effects to improve waste arisings and management (see Table 3, “2050 CE” tab). 65% was chosen to reflect the 50% fall in material consumption, which is assumed to follow through to a similar fall in waste arisings, in addition to the 15% reduction expected in the BAU scenario.

2. Of the waste arising by material type, 20% of tonnages were assumed to be sent to incineration and 5% were assumed to be sent to landfill. The remaining 75% are split between recyclate managed in Scotland and exported for reprocessing.

Driver: Proportion of recyclate exported

1. Export for reprocessing is halved compared to BAU scenario as reprocessing and remanufacturing technology is promoted in Scotland through CE policies (see Table 3, “2050 CE” tab).

Annex 2 Data quality and sensitivity analysis tables

Table A2.1 Data Quality table for material flows of domestic production in Scotland

Material	Source	DQ Score	Justification
Chemical and industrial materials	PRODCOM 2012	Medium	Referenced secondary data for the UK
Construction material	Eurostat material flow accounts 2012, non-metallic minerals. Assumed 91% C&D material, based on C&D: other minerals waste ratio. Then scaled down to Scotland level.	Medium	Referenced secondary data for the UK
Ferrous metal	Based on WRAP impacts model assumption of 74% domestic production. Original source is the Courtauld packaging data.	Low	Assumption derived from uncertain UK source
Food and plants	WRAP 2014, Keith James, UK Food flow 2012	High	Good UK source
Glass	http://www.britglass.org.uk/publications/uk-glass-manufacture-a-mass-balance-study-2008	Medium	Old UK source
Healthcare equipment	Production data is unknown	Low	Data missing
Household goods	Furniture flows, WRAP 2011. Similar to WRAP impacts model assumption of 10% domestic production.	Medium	Good UK source but only covers furniture products
Machinery	WRAP WEEE model (2012) . Assumes 10% of market is domestic production, as does the WRAP impacts model.	Medium	Good UK source but makes general assumption about size of domestic market
Minerals	Eurostat material flow accounts 2012, non-metallic minerals. Assumed 9% other mineral material, based on C&D: other minerals waste ratio. Then scaled down to Scotland level. PLUS Fossil fuel Eurostat material flow accounts figures.	Medium	Referenced secondary data for the UK
Mixed metals	Based on WRAP impacts model assumption of 74% domestic production. Original source is the Courtauld packaging data.	Low	Assumption derived from uncertain UK source
Non-ferrous metal	Based on WRAP impacts model assumption of 64% domestic production. Original source is the European Aluminium Association (2008)	Low	Assumption derived from uncertain UK source
Paper	Euro stat (2012) data. Compared to CPI production stats (4.5Mt for up, 382,263t when split by Scotland's population). Very similar. http://www.paper.org.uk/information/pages/statistics.html	Medium	Referenced secondary data for the UK
Plastics	PRODCOM (2012)	Medium	Referenced secondary data for the UK

Rubber	PRODCOM 2012 - synthetic rubber, latex and non-latex for UK, scaled down to Scottish level using population spilt	Medium	Referenced secondary data for the UK
Textiles	Taken from summary of PRODCOM data for 2011, as used in the Textile flow report and scaled from UK to Scottish level using population split.	Medium	Referenced secondary data for the UK
Vehicles	ONS PROD COM 2012 data. Note excludes ships	Medium	Referenced secondary data for the UK
Wood	EUROSTAT Material flows accounts for 2012 Domestic extraction used (wood) for UK = 5963000t	Medium	Referenced secondary data for the UK

Table A2.2 Data Quality table for material flows of domestic production in Scotland

Material	Source	DQ Score	Justification
Chemical and industrial materials	ZWS (2014) Carbon Metric	Low	Poorly understood carbon impacts and heterogeneous category
Construction material	ZWS (2014) Carbon Metric	Low	Poorly understood composition which is likely to vary greatly from year to year, which can't be reflected in these carbon factors
Ferrous metal	ZWS (2014) Carbon Metric	Medium	Extrapolation of raw material and recycled content impacts from partial recycled steel factors (reflecting the reality that steel is mainly manufactured from material with at least some recycled content). Production source from 1997.
Food and plants	ZWS (2014) Carbon Metric	Medium	Some key data points estimated from single studies. All food considered with a single impact figure.
Glass	ZWS (2014) Carbon Metric	Low	Data source from 2003. Recycling to glass fibre is not included.
Healthcare equipment	ZWS (2014) Carbon Metric	Low	Highly heterogeneous waste stream. Composition taken from 2005 study.
Household goods	ZWS (2014) Carbon Metric	Medium	Extrapolated from compositional data
Machinery	ZWS (2014) Carbon Metric	Low	1 study by UN aggregated data.
Minerals	ZWS (2014) Carbon Metric	Low	Some older sources, highly variable waste stream and composition not well understood.
Mixed metals	ZWS (2014) Carbon Metric	Medium	Extrapolation of the f and non-f factors

Non-ferrous metal	ZWS (2014) Carbon Metric	High	Based on high quality European data
Paper	ZWS (2014) Carbon Metric	Medium	Includes recycled content in production figure (reflects reality that nearly all paper manufacturing includes material with recycled content). This means there is a double count of avoided production impacts in the recycling carbon factors.
Plastics	ZWS (2014) Carbon Metric	Medium	Based on 1 study from 2002
Rubber	ZWS (2014) Carbon Metric	Medium	Data from 2004
Textiles	ZWS (2014) Carbon Metric	Medium	Textiles data is good quality. Shoe data from one study in the USA.
Vehicles	ZWS (2014) Carbon Metric	Low	Impacts from a passenger car only (category also includes push bikes, motorbikes and planes).
Wood	ZWS (2014) Carbon Metric	Medium	Some key data points estimated from single studies.

Table A2.3 Sensitivity analysis of the assumption that a 2050 circular economy in Scotland would achieve 50% reduction in material consumption

Indicator	2050 CE scenario, main study (50% material consumption reduction)	Sensitivity test 1 (25% material consumption reduction)	difference to standard model	Sensitivity test 2 (75% mat consumption reduction)	difference to standard model	Unit
Total material consumption	69,088,377	103,632,566	50%	34,544,189	-50%	Tonnes
Total waste arisings	4,097,247	4,097,247	0%	4,097,247	0%	Tonnes
Territorial carbon impact of total material use	15,087,556	23,764,552	58%	7,921,517	-47%	tCo2eq
Territorial carbon impact of waste	-385,851	-385,851	0%	-385,851	0%	tCo2eq
Total *territorial* carbon impact	**14,701,705**	**23,378,701**	59%	**7,535,666**	-49%	tCo2eq
Consumption carbon impact of DMC	56,449,521	84,680,669	50%	28,226,890	-50%	tCo2eq

Consumption carbon impact of waste	-948,999	-948,999	0%	-948,999	0%	tCo2eq
Total consumption carbon impact of DMC	**55,500,522**	**83,731,670**	51%	**27,277,890**	-51%	tCo2eq

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