SMFA Model

Update with 2018 data

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Contents

Glossary

AQPI	Air Quality Pollutant Inventory
DMC	Domestic Material Consumption
DE	Domestic Extraction
DMI	Direct Material Inputs
MFA	Material Flow Accounts
NFR	Nomenclature for Reporting
PRTR	Pollutant Release and Transfer Register
PTB	Physical Trade Balance
RMC	Raw Material Consumption
RME	Raw Material Equivalent
RMI	Raw Material Inputs
SMFA	Scottish Material Flow Accounts

1 Introduction

In 2019, Zero Waste Scotland commissioned Eunomia to develop a Material Flows Account (MFA) for Scotland[1]. The aim of the MFA was to evaluate, for the first time, the flow of materials in and out of the Scottish economy in a format which could inform and measure progress towards a circular economy. As described in Zero Waste Scotland's website[2]:

THE MFA PAINTS A PICTURE OF THE SCALE AND NATURE OF SCOTLAND'S CONSUMPTION BY CALCULATING ALL THE RAW MATERIALS USED TO MAKE PRODUCTS (E.G. OIL AND METAL ORES) AND ALL THE FINISHED PRODUCTS WE CONSUME, WHETHER MADE IN SCOTLAND OR IMPORTED.

SIMPLY PUT, THE ANALYSIS QUANTIFIES SCOTLAND'S MATERIAL FOOTPRINT FOR THE FIRST TIME.

Eunomia was commissioned by ZWS to update the model with 2018 data, as well as the user guide. This report describes the update process: the main changes in terms of data (chapter 2) and the main indicators and findings (chapter 3).

[1] Zero Waste Scotland, Scottish Material Flow Accounts. Technical Report (2021)

[2] https://www.zerowastescotland.org.uk/research-evaluation/material-flow-accounts-mfa

2 Main changes 2018 vs previous years

2.1 Biomass data

Asides from the update of 2018 data, there have been some retroactive updates of most 2017 data and some of 2016 data; all other years have remained the same.

2.2 Minerals & Mineral Extraction

Asides from the update of 2018 data, there were no retroactive updates to previous years.

2.3 Fossil Fuel Data

Asides from the update of 2018 data, there have been some retroactive updates from 2014 to 2017 for indigenous production data, from 2011 to 2017 for imports from the rest of world data, from 2011 to 2017 for imports from rest of UK data and from 2011 to 2017 from exports to rest of world.

2.4 Waste Data

Asides from the update of 2018 data, there were no retroactive updates to previous years.

2.5 Emissions Data

Asides from the update of 2018 data, total emissions data has been updated for the period 2011-2017. Emissions from specific sources data has been retroactively updated for all pollutants except PM_{10}. Scotland's GHG inventory has been retroactively updated for CO_2, CH_4, HFCs, and N_2O for the period 2011-2018. Finally, the PRTR pollutant release data for 2017 was retroactively updated because it had only accounted for releases to water and had omitted releases to air.

There is a missing data point within the 2018 PRTR Pollutant Transfers dataset for Nitrogen which has been highlighted in yellow. Eunomia and Zero Waste Scotland are in the process of sourcing this data point from Defra.

2.6 Other Data

Asides from the update of 2018 data, there were no retroactive updates to previous years.

2.7 Comext Export and Import Data

Asides from the update of 2018 data, there were no retroactive updates to previous years.

2.8 Raw Material Equivalent (RME) Export and Import Data

RME coefficients in the supplementary model were updated to the 2018 values.

2.9 Guidance

The accompanying user guide has been updated to reflect any changes to the data sources, as well as to improve the clarity of certain sections. Asides from updates to the hyperlinks, the main changes are:

- The Pollutant Release and Transfer Register (PRTR) data has been obtained from Defra instead of the EU database. There is the potential to use Scotland's PRTR database for future years, but it was not available at the time.
- Added data sources for salt spreading and disposal of sewage sludge on land.
- Updated the detailed instructions for the Comext Export and Import data due to changes in the layout of the EU Trade database.
- Added instructions to update the charts comparing with international indicators.

3 Findings

3.1 Key indicators

In addition to estimating the material flows, we have also estimated the key MFA indicators for Scotland using the SMFA model.

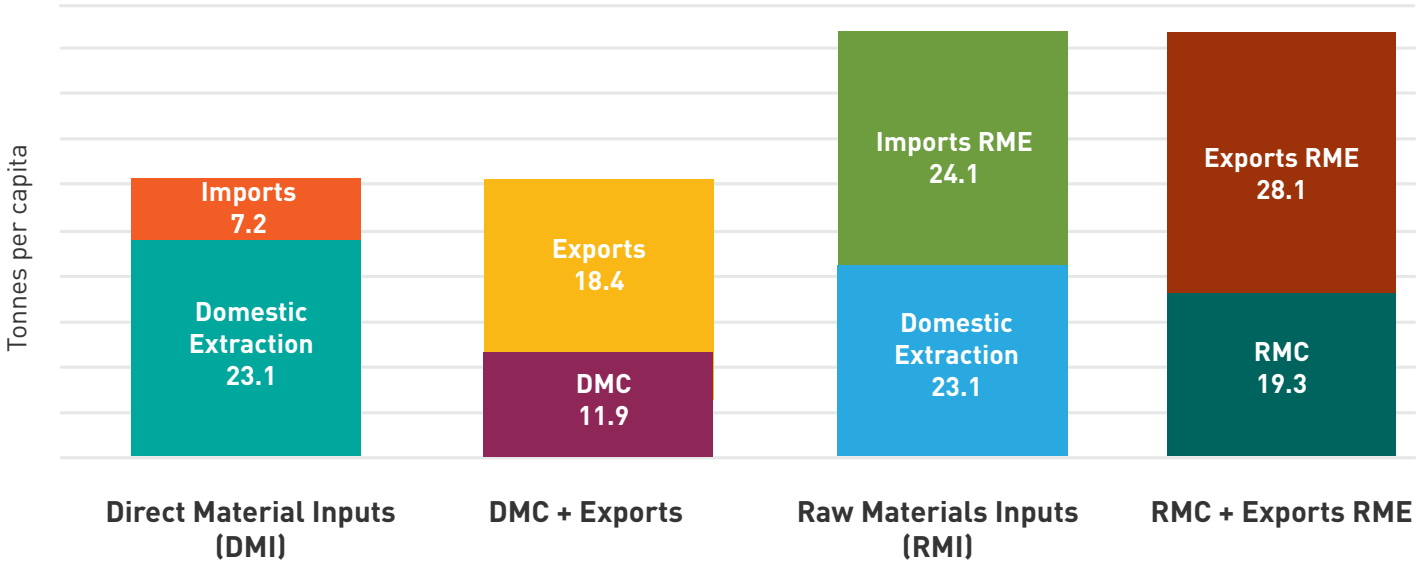
These are discussed below. Table 1 and Figure 1 present the key MFA indicators for Scotland in tonnes per capita for 2018.

Table 1: Scotland's DE, DMI and DMC (tonnes per capita), 2017 vs 2018

Year	DE	DMI	DMC
2017	22.8	30.8	12.2
2018	23.1	30.3	11.9

The estimated Domestic Extraction (DE) in 2018 is 23.1 tonnes per capita, while the estimated Direct Material Inputs (DMI) and Domestic Material Consumption (DMC) are 30.3 and 11.9 tonnes per capita, respectively. It can also be observed that the estimated DMC is lower than DE, implying that Scotland is a net exporter of materials and products due to higher export of fossil fuels/energy carriers than imports.

Figure 1: Key MFA Indicators (2018)



In terms of RME indicators, the estimated Raw Material Inputs (RMI) for Scotland in 2018 is 47.2 tonnes per capita, while the estimated material footprint (Raw Material Consumption per capita) is 19.3 tonnes per capita.

This seems to indicate that Scotland is quite a material intensive economy with significant extraction of fossil fuel/energy carrier materials.

Table 2: Scotland's RMI and RMC (tonnes per capita), 2017 vs 2018

Year	RMI	RMC
2017	46.5	18.4
2018	47.2	19.3

Figure 2: Trends in Domestic Extraction, DMI and DMC (2011-2018)

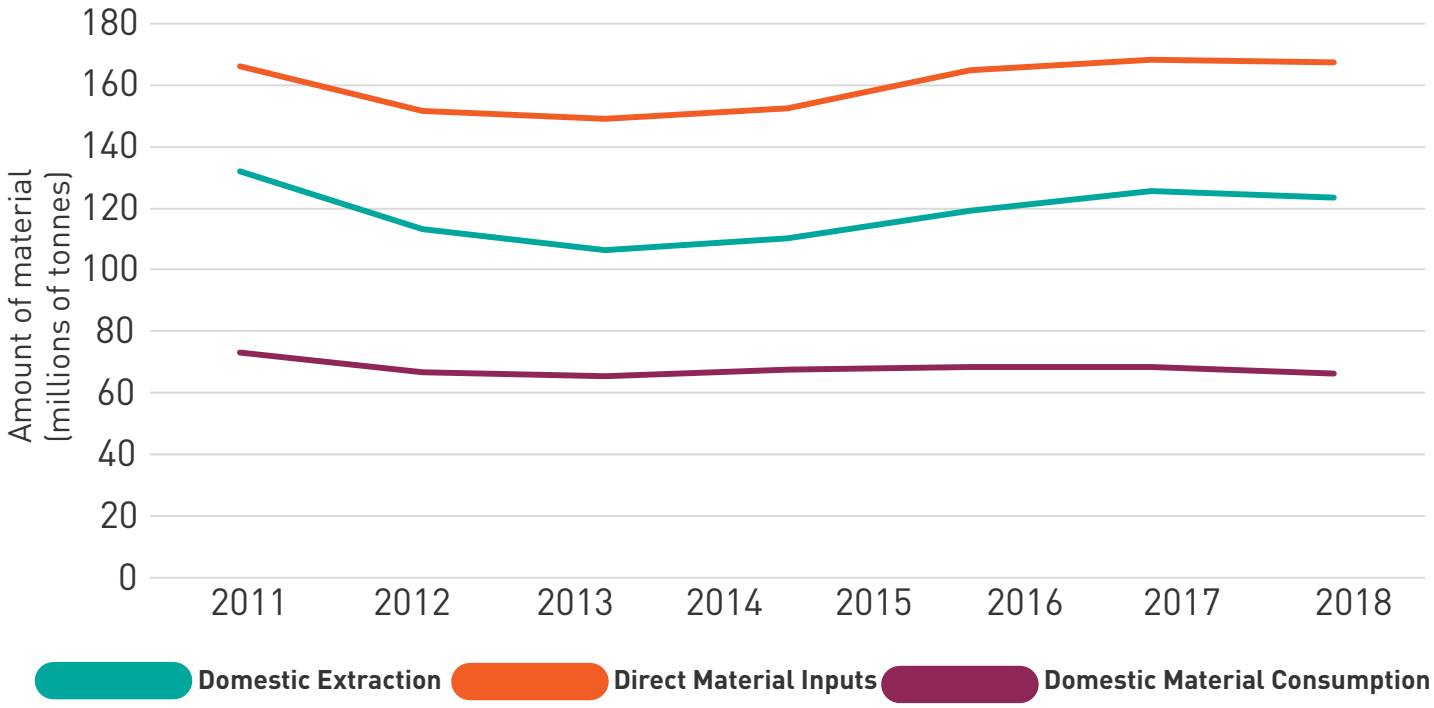
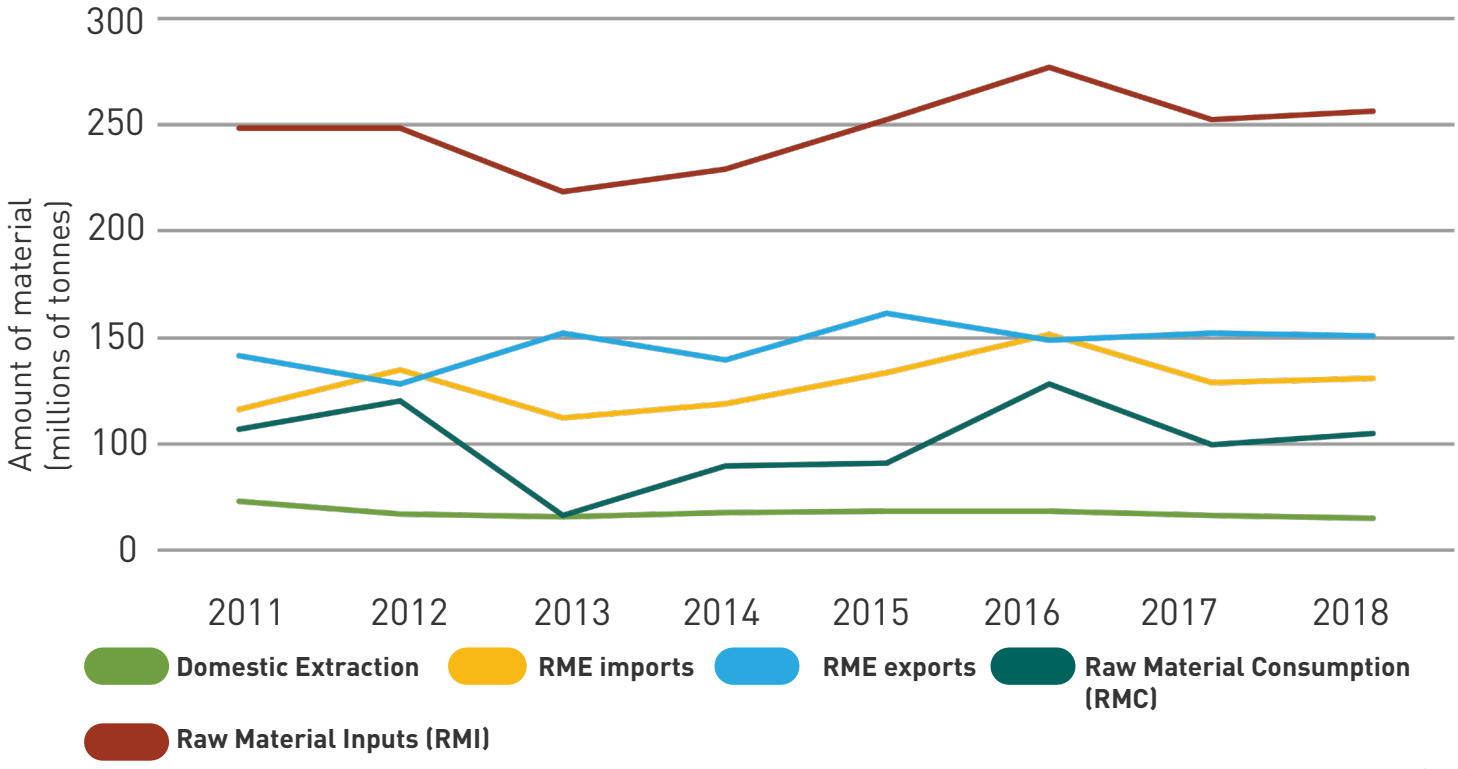


Figure 2 shows the trends in DE, DMI and DMC between 2011 and 2018. While DMI figures have remained the same, DMC has slowly decreased over the years, suggesting a decoupling between the extraction and the consumption.

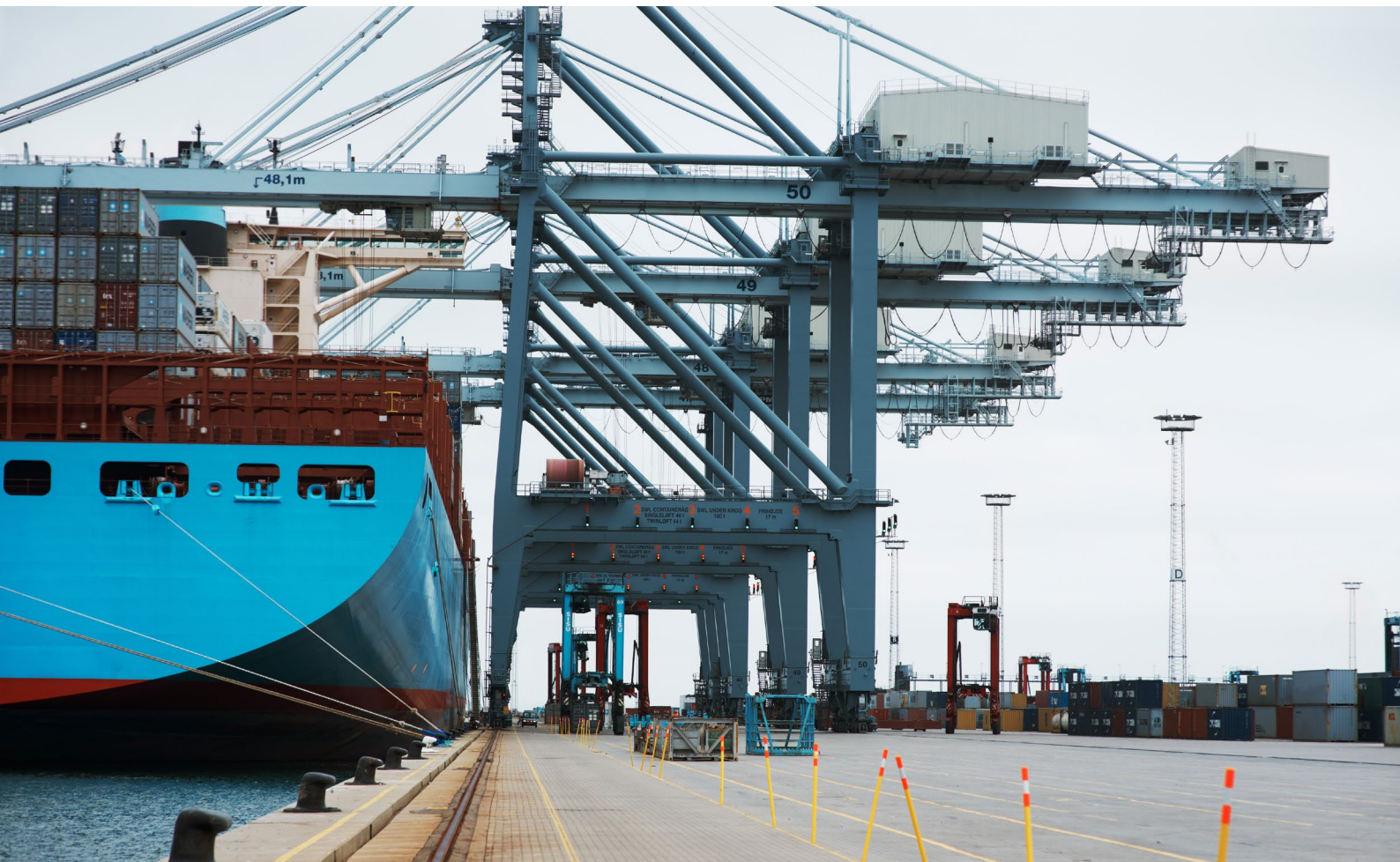
Figure 3: Trends in DMC, RMC, RMI, and RME Trade (2011-2018)



On the other hand, Figure 3 represents the trends in DE, RME imports & exports, RMC, and RMI between 2011 and 2018. Similar to the domestic indicators, the RME indicators generally appear to have decreased leading up to 2013, increased up to 2016, and then remained stable until 2018. That is with the exception of RME exports, which seems to be following the inverse of that trend. We can also see that the disparity between RMC and RMI is even larger than the disparity between DMC and DMI; emphasizing the sheer amount of materials that are required for Scotland's exports.

This sharp variability of the raw material equivalent time-series' compared to the domestic time-series' can almost entirely be attributed to the variability of the raw material equivalent coefficients Eurostat has calculated for a single material flow category: MF22. Non-Ferrous Metals.

These coefficients are meant to represent an average amount of embedded materials for traded European goods. The amount of embodied materials in traded goods depends on the trading partner and the respective technologies and processes they employ. Changes in these coefficients over time are meant to represent changes in trading partners or the production technologies being used.

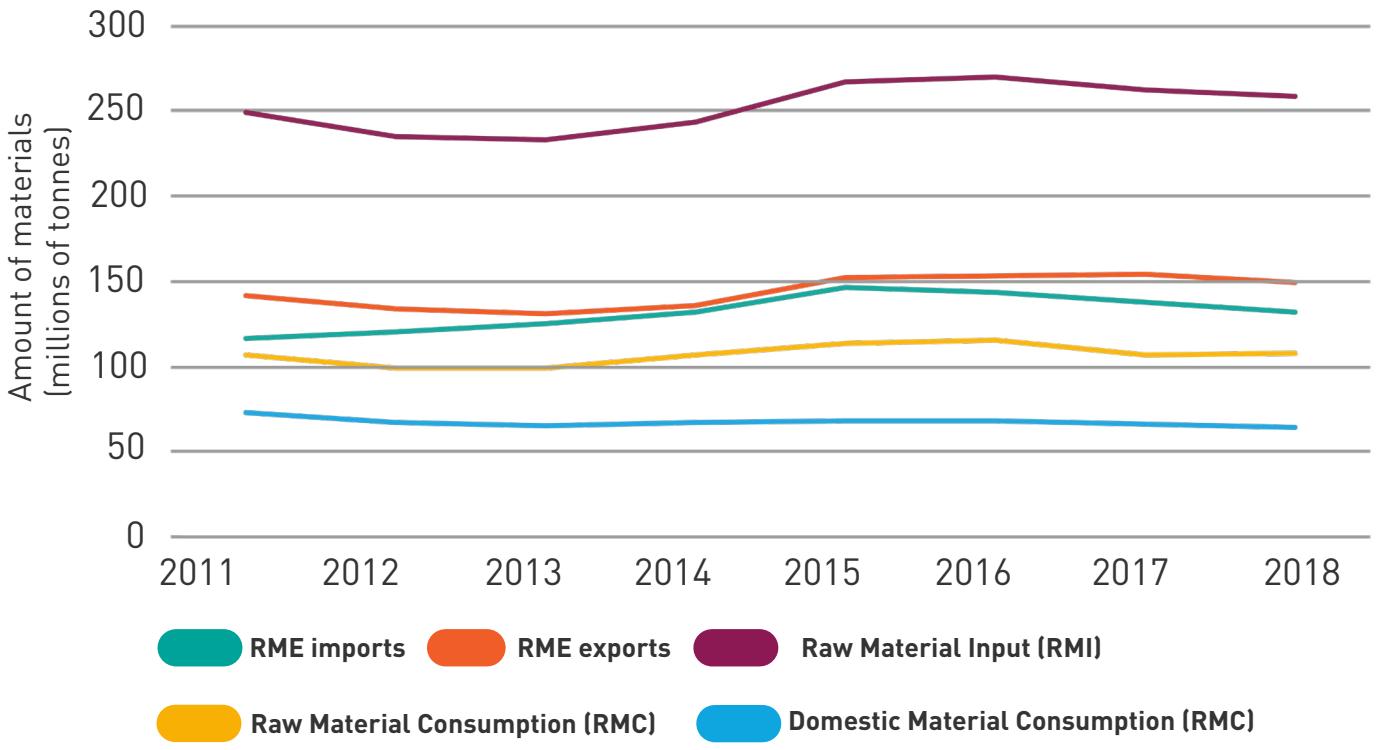


It is unclear why the RME estimates for MF22. Non-Ferrous Metals changed so much over this period, and attempts have been made to reach out to Eurostat for an explanation. Hopefully, we will be able to share an explanation in a future MFA update.

To correct for this, a method of data-smoothing called Exponential Smoothing was applied to replace the average RME impact coefficients for non-ferrous metals over the 2011-2018 period. This method was deemed preferable over other common methods as there are relatively few observations in this time series, we wanted to avoid speculation around underlying trends, and we wanted to avoid the subjective placement of weights as much as possible. This method necessitates the implementation of a smoothing constant, which may be subjective, so we utilized a non-linear optimization function to choose this parameter for us[3] . This method also assumes that the earliest data point (2011) is "true".

The resulting smoothed RME data can be seen in Figure 4 below

Figure 4: Smoothed Trends in DMC, RMC, RMI, and RME Trade (2011-2018)

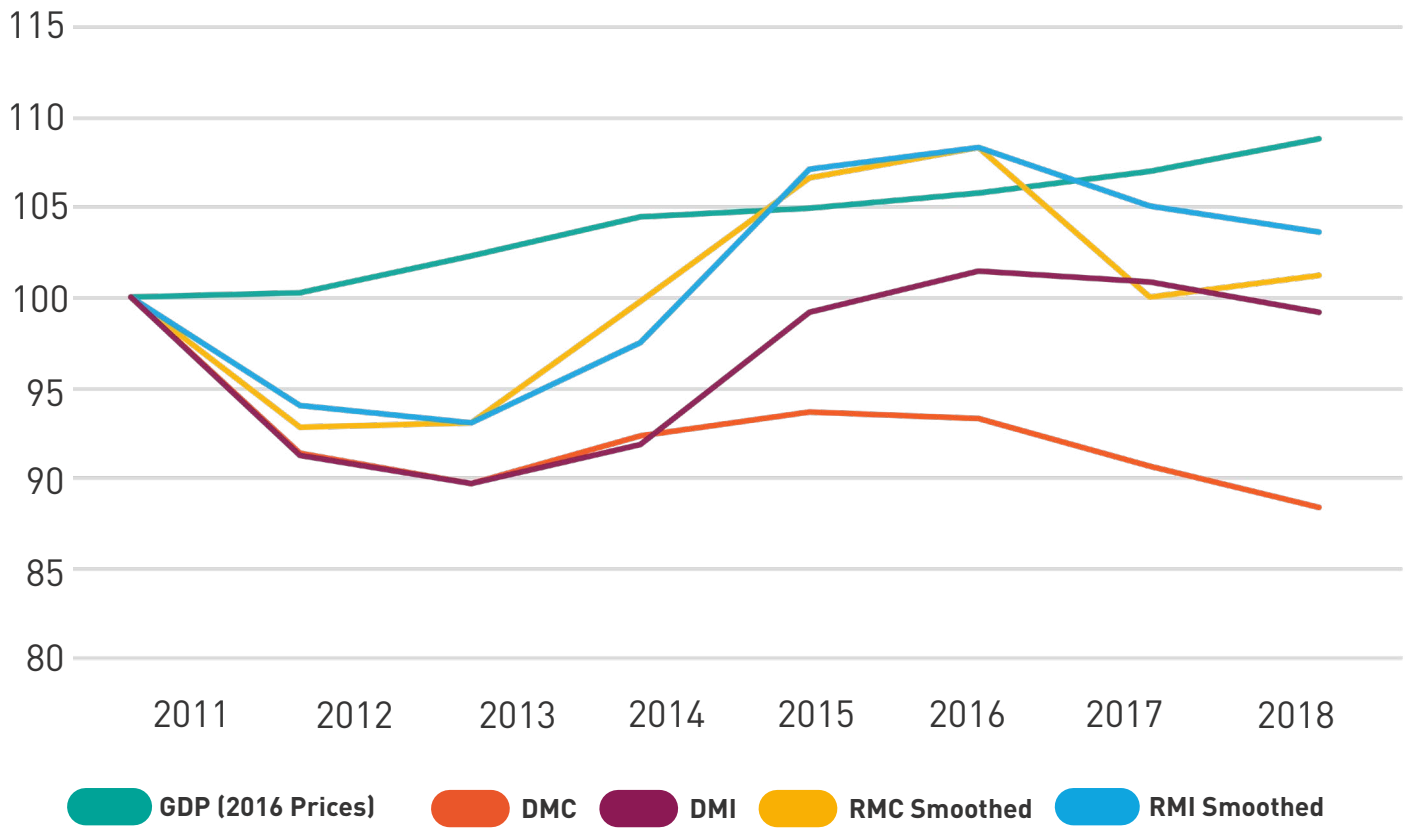


[3]The function minimized the three common measures of deviations (Mean Absolute Deviations, Mean Absolute Percent Errors, and Mean Squared Errors) from the original data and output three smoothing constants. The constant can take a value between zero and one, and the function output zero twice and 0.05 once. Because of this, a parameter of zero was chosen to best fit the data. In effect, this applied a uniform material impact coefficient to the Non-Ferrous Metals category across the 2011-2018 period.

Smoothing these data series allows us to more easily identify trends in Scotland's consumption. After smoothing the variability in the RME coefficient for MF022; RMI, RME and RMC are relatively stable between 2011 and 2018.. The above figure shows that the gap between RMI and RMC is even greater than the gap between the DMC and DMI, further emphasizing the importance of considering exports when analysing Scotland's material needs.

An index of GDP and each of our primary material flow indicators is presented in Figure 5 below.

Figure 5: Indexed Trends in GDP, DMC, DMI, RMC, and RMI (2011-2018)



Whether or not Scotland is decoupling its GDP growth from resource use is largely up to how you define Scotland's material footprint. If we take the most limited view of defining it only as the materials we directly consume (DMC), it appears decoupling is starting to take place.

If you consider the products that Scotland is exporting to be contributing to GDP growth (DMI), the relationship is less clear as there have been convergent and divergent trends over time. If you believe the Scottish economy and Scotland's standard of living are also dependent on the materials used to create the products

we import (RMC and RMI), the evidence of a decoupling is even weaker with material productivity actually falling below 2011 levels in 2015-2016. Regardless, as we are observing a relatively short time period, caution should be taken when making decoupling claims. One trend that is clear is the increasing divergence between DMC and the rest of the material flow indicators. Its divergence from DMI can be explained by increasing fossil fuel exports over this time period; while its divergence from the RME indicators is primarily being caused by the increased offshoring of production to other countries (which includes the rest of the UK here).

3.2 Comparison with other MFAs

Figure 6 and Table 3 below show how Scotland's key indicators compare with the UK and other EU countries. Scotland's domestic extraction per capita of 23.1 is within the highest in Europe, well above the EU-28 average of 11.3 and the UK average of 6.6. Norway has been excluded from the chart since it has the highest value at 60.9.

Figure 6: Per Capita Domestic Extraction for Scotland and other European Countries, 2018

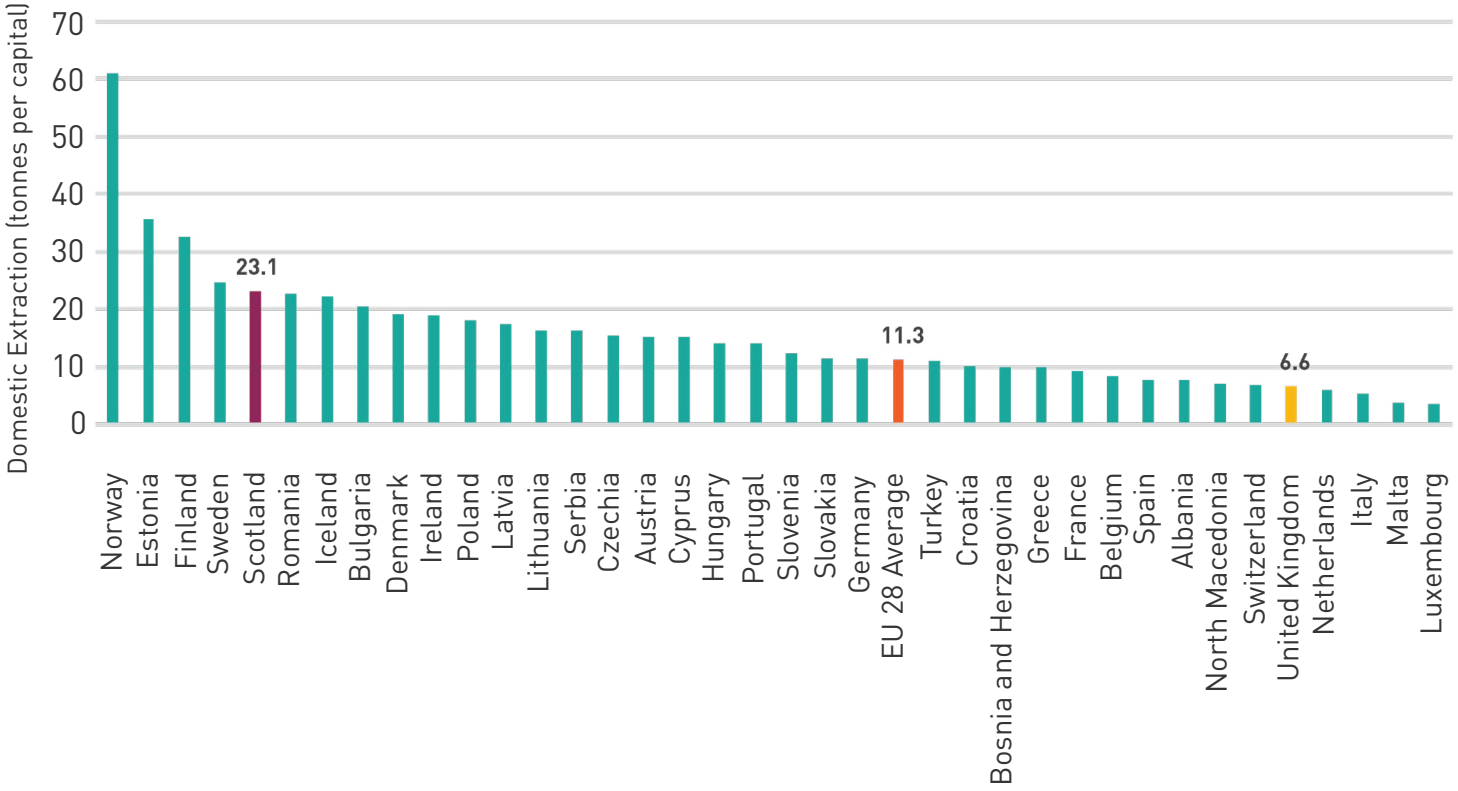
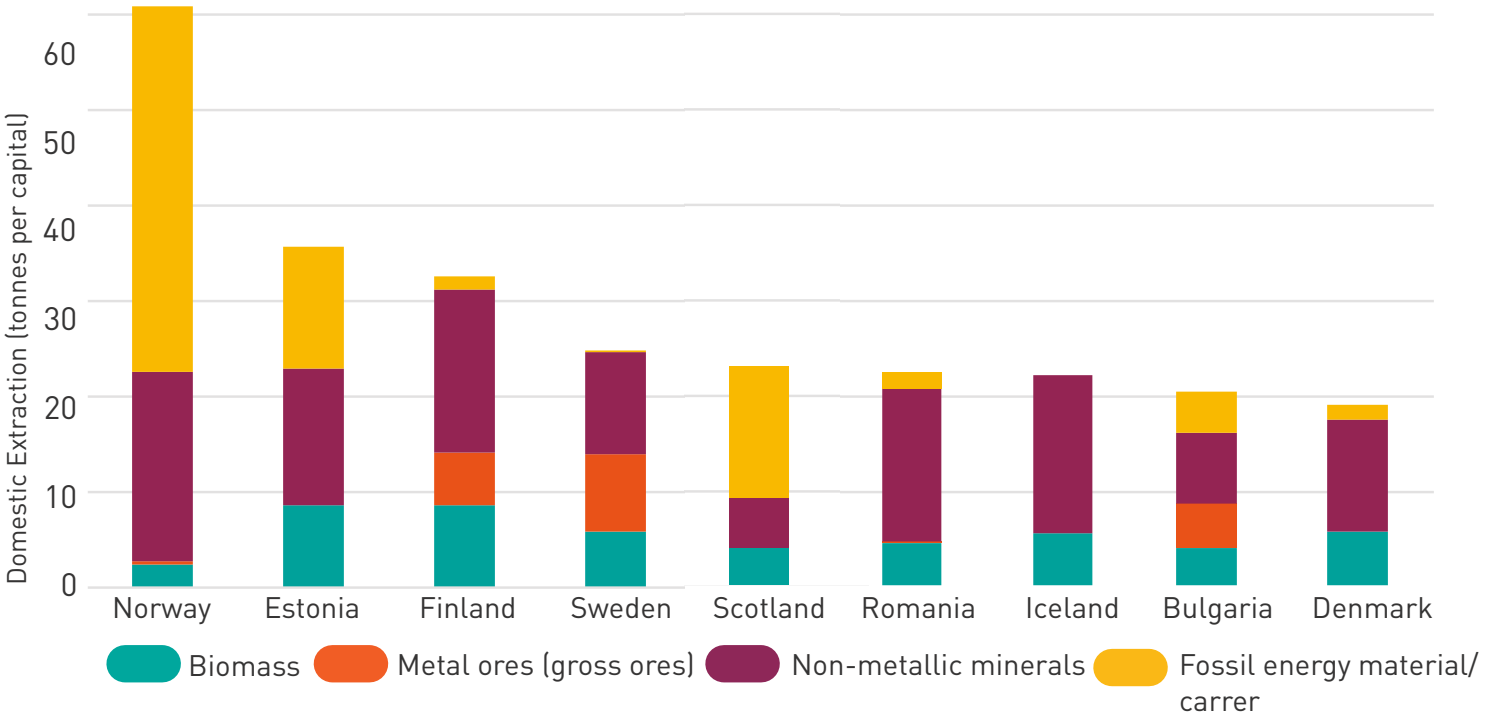


Table 3: DE of Scotland, UK and EU28 average (tonnes per capita), 2017 vs 2018

Year	Scotland	UK	EU28 average
2017	22.8	6.7	11.3
2018	23.1	6.6	11.3

When comparing with the other countries with high DE levels, Figure 7 shows that most of them have a high component of non-metallic minerals, while Scotland's highest component in fossil energy materials/carriers.

Figure 7: Domestic Extraction per capita comparison of EU nations (+ Norway) with the highest DE levels (largest to smallest), 2018



However, in terms of DMC, Scotland's DMC of 11.9 is slightly below EU-28 average of 13.4 and above UK's DMC of 8.6.

Table 4: DMC of Scotland, UK and EU28 average (tonnes per capita), 2017 vs 2018

Year	Scotland	UK	EU28 average
2017	12.2	8.6	13.3
2018	11.9	8.6	13.4

Figure 8: Per Capita Domestic Material Consumption for Scotland and other European Countries, 2018

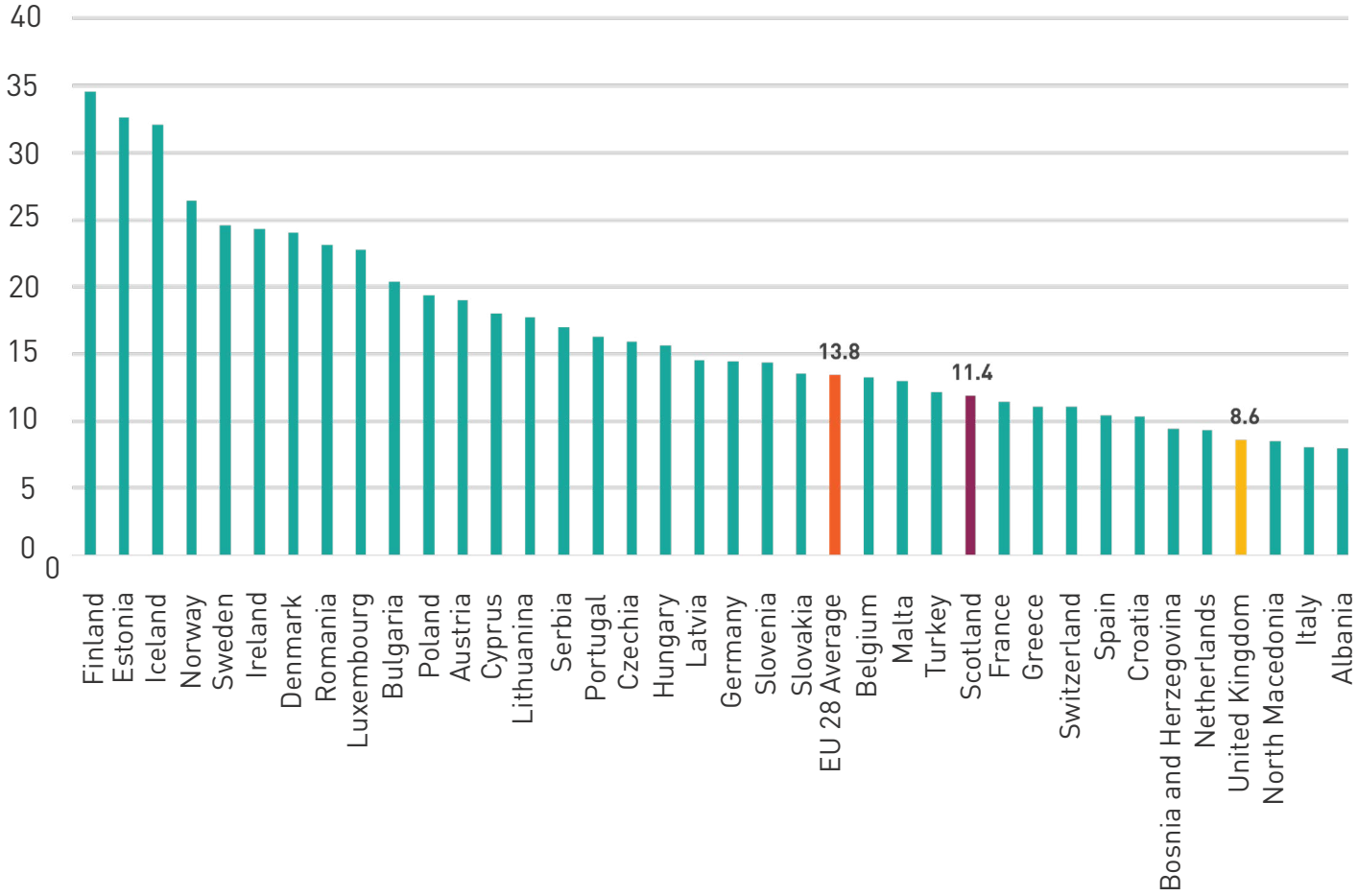


Figure 9: Comparison of Scotland's DE and DMC per capita with EU28 (left) and UK (right)

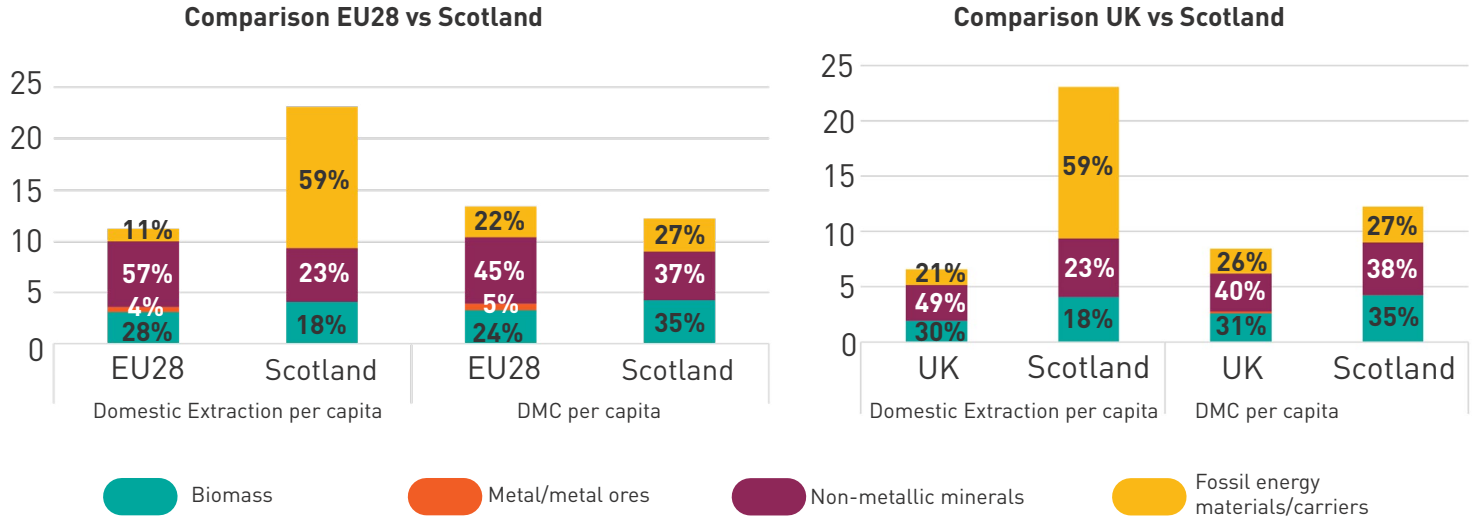


Figure 9 Compares Scotland's DE and DMC per capita with the EU28 and UK values. We can see in the component breakdown that the component for fossil energy materials/carriers in Scotland is much higher.

Figure 10: Per Capita Raw Material Consumption for Scotland and other European Countries, 2018

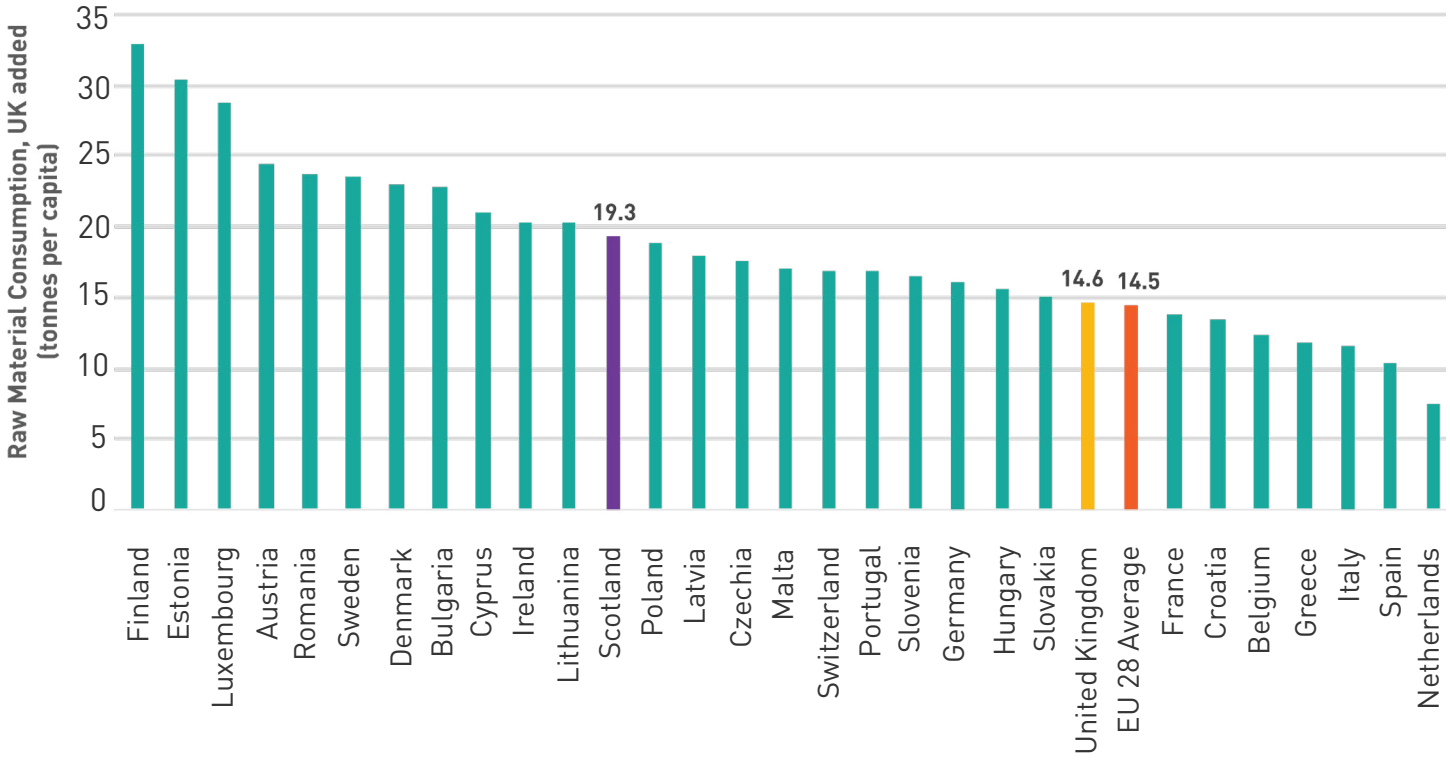


Figure 10 compares the per capita material footprints of the European nations, Scotland, and the UK average. In 2018 the UK stopped reporting its material footprint to the Eurostat dataset so this data point was taken from the UK MFA done by the University of Leeds[4]. Also, the above graph shows the EU 27 average, which differs from the EU 28 average as it excludes the UK.

Here we can see that Scotland has the 12th highest material footprint per capita in Europe; much higher than the UK and EU average which rank 23rd and 24th respectively. By these accounts, Scotland's per capita material footprint was roughly 32% higher than the UK average.

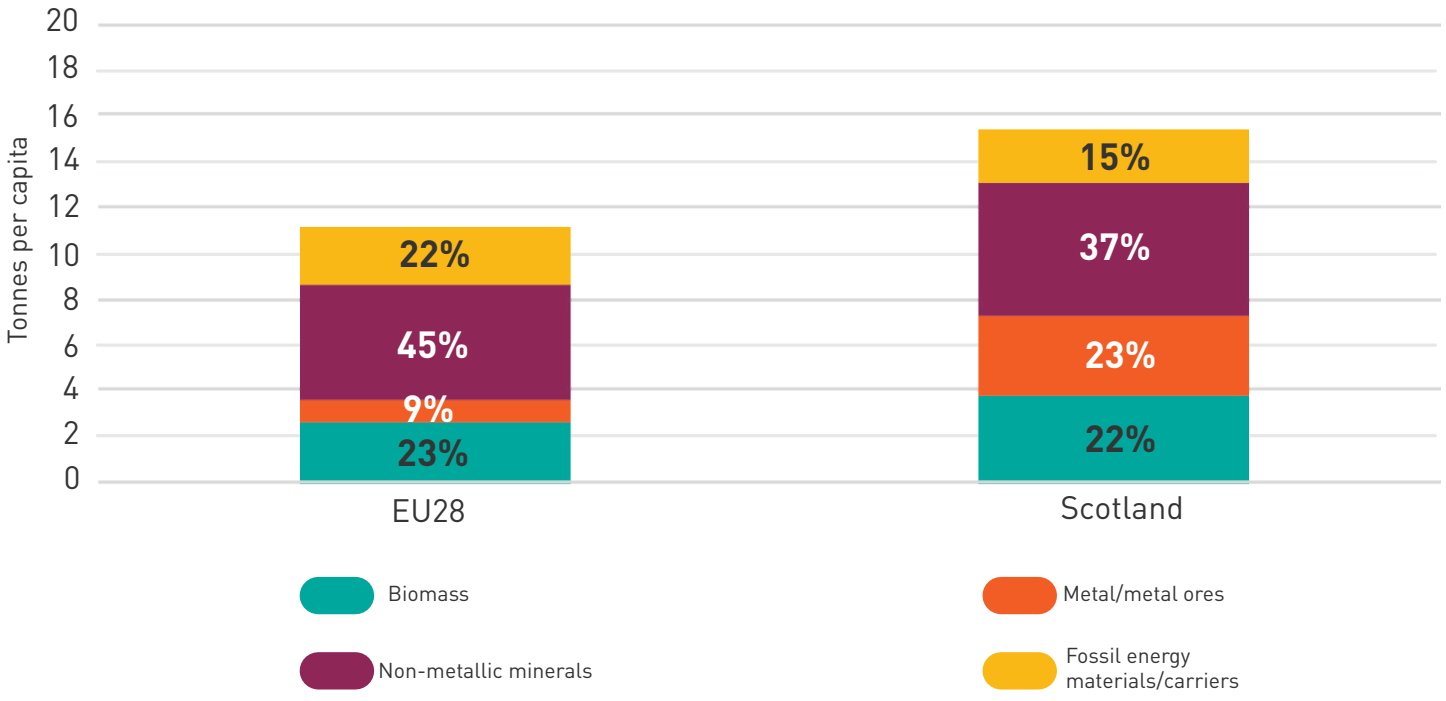
Figure 11 below shows the breakdown of RMC by component, with Scotland's metal and metal ores being significantly higher. Here we are comparing with the EU 28 average.

[4]ONS – Material Footprint in the UK 2018

Table 5: RMC of Scotland, UK and EU28 average (tonnes per capita), 2017 vs 2018

Year	Biomass	Non-metallic minerals	Metal/ores	Fossil energy materials/ carriers	RMC
2017 Scotland	4.562	4.482	6.149	3.202	**18.4**
EU28 average	3.423	1.474	6.0328	3.173	**14.1**
2018 Scotland	4.663	4.518	7.195	2.970	**19.3**
EU28 average	3.208	1.326	6.345	3.114	**14.0**

Figure 11: RMC per capita, Scotland vs EU-28 average

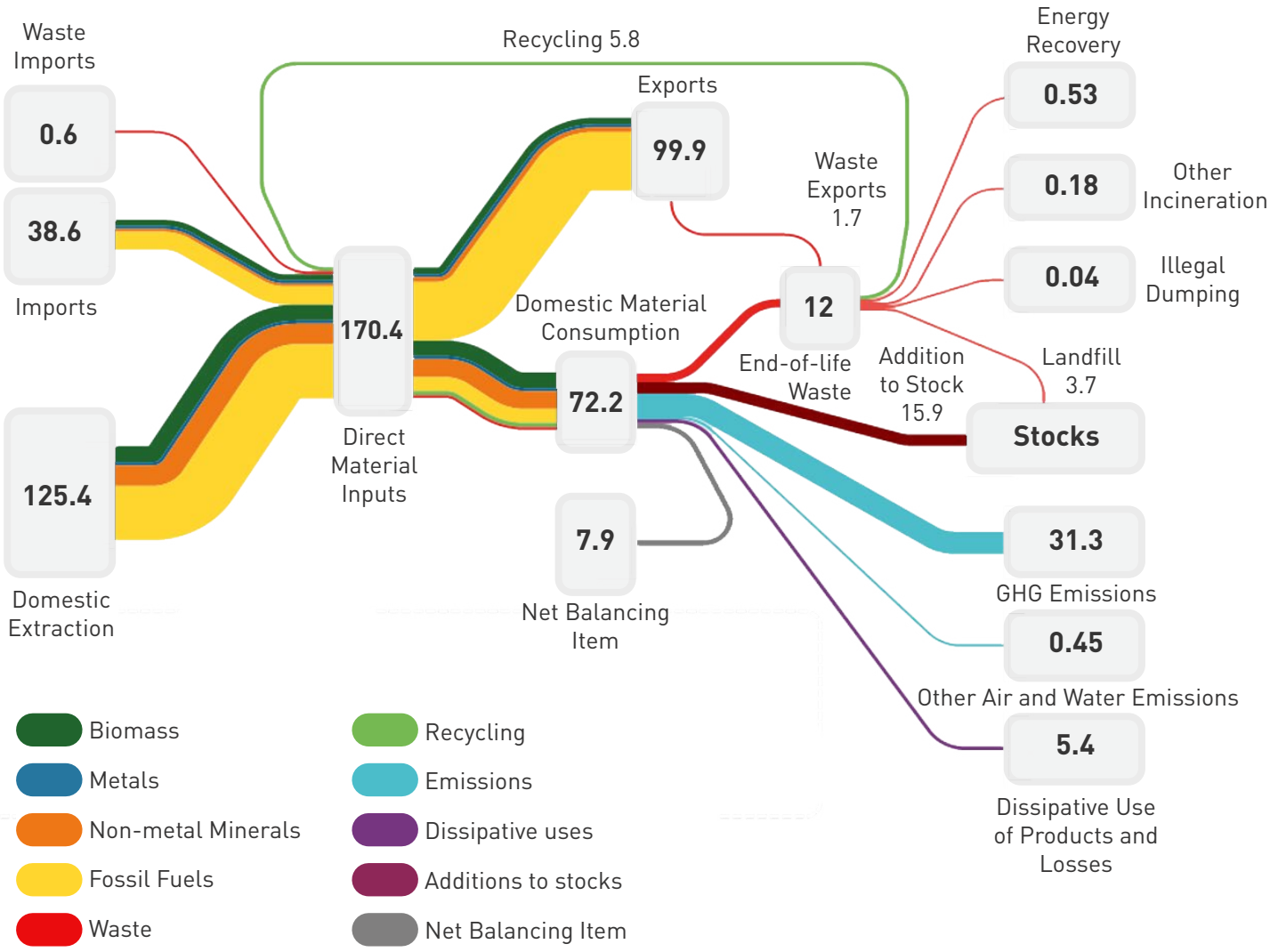


3.3 Sankey Diagram

Figure 12 presents Scotland's material flows using a Sankey diagram.

Figure 12: Material Flow Diagram for Scotland 2018

Units: Million tonnes **Year: 2018**



3.4 Overview of findings

Key findings from the above analysis are listed below:

- **Extraction of fossil energy materials/carriers accounts for around 60% of domestic extraction in Scotland, while extraction of metal ores is zero;**
- **Scotland is a net exporter of materials, with exports with about x2.5 more exports than imports;**
- **Fossil fuels are by far the main import for Scotland with biomass (and associated semi-finished and finished products) second;**
- **Main exported materials for Scotland are fossil energy material/carrier products, which accounts for just under 80% of Scottish exports;**
- **Scottish DMC per capita has declined overall since 2011;**
- **Scotland displayed higher domestic extraction per capita compared to the UK and EU-28 but had lower DMC in per capita terms than the EU-28 average in 2018;**
- **Recycling makes up 5.8 million tonnes of the 170.4 million tonnes of Direct Material Inputs, representing a 3.4%. When against the 12 million tonnes sent to end-of-life waste, the share of recycling is 48%.**
- **Scotland's exports are higher than the domestic material consumption; Scotland consumes internally less than half of its direct material inputs.**

4 Conclusions

4.1 Scotland's indicators

Overall we can observe a slight decrease of Scotland's DMI and DMC per capita in 2018 vs 2017:

- DMI decreased from 30.8 to 30.3 tonnes per capita; and
- DMC decreased from 12.2 to 11.9 tonnes per capita.

4.2 Recommendations

Some key recommendations to improve data quality and reliability for the MFA model would be:

- As discussed in section 2.9, to consider using Scotland's own PRTR databased instead of Defra's.
- To consider accounting for $PM_{2.5}$ in the section of the model for Scotland's Air Quality Pollutant Inventory (AQPI), under the 'Emissions' tab. Following the latest EU MFA guidance, $PM_{2.5}$ would fall under the material category MF71E 'Particles (e.g. PM10, Dust)' and $PM_{2.5}$ data is readily available within Scotland's AQPI. For the 'Emissions from Specific Sources' section within the model, the Nomenclature for Reporting (NFR) Codes for $PM_{2.5}$ would be the same as those for PM_{10}.

Fossil energy materials/carriers continues being the main component of the material flows, especially with regards to domestic extraction, imports and exports.

Finally, the impact of Brexit needs to be considered in terms of future reporting, especially with regards to Eurostat data. This will be addressed in a separate report.

Annex 1: Peer Review of Scottish Material Flow Account

By Dr.Robin Curry, Queen's University Belfast

This is a qualitative peer-review of the Scottish Material Flow Account. The peer review will focus on the following areas, as set out by Zero Waste Scotland via email dated 15th July 2022:

1. The Supplementary Model: the process of applying the Eurostat RME coefficients and where the downscaling may be leading to inaccuracies.
2. A review of the balancing item calculations and methodology.

1.Technical Report 'SMFA Model. Update with 2018 data'.

This report describes the update process, the main changes in terms of data, the main indicators, and findings, and concludes with recommendations on:

- Use of Scotland's own PRTR register;
- Inclusion of $PM_{2.5}$ in the Emissions section of the model.

Both are common-sense recommendations which I recommend are implemented.

2. Review of supplementary model 'SMFA Supplementary Model 2018 v2.0'.

The RME Coefficients for Imports and RME Coefficients for Exports are derived from the EU RME Tool [Input data country RME tool - October 2021(rev.20Dec)]. I can confirm that the use of the Eurostat RME coefficients in this way is the correct approach.

3. Review of the balancing item calculations and methodology.

I can confirm that the methodology used is correct. One point on some of the data provided in the Annex:

Moisture content of crops.

The Eurostat Annex states that these are 'Assumed European Averages'. I have checked the 'Moisture Content at Harvest' figures from the 'Balancing Items Calc' tab, in the case of cereals this is 14%

The Eurostat Annex has:
Cereals/other: 10%
Wheat: 14%

Could you confirm if the data used in the balancing items for moisture content of crops was the assumed European Averages, or Scotland specific data?

Eunomia's Response: V2.0 used 14% which we believe was the value when the model was first developed and we assumed that the values would not change over time. We have now updated the model using 10% which represents a very small change in the balancing items -0.2% reduction of the balancing item on the output side. This does not affect the main indicators such as DMC and RMC. We have added a note on top of the sheet that the values need to be check in case Eurostat updates them.

4. Balancing Items.

In the balancing items tab, the 'Balancing items: input side', does not contain data for 'MF813 Nitrogen for Haber-Bosch process'. I assume that this is because there is no ammonia production in Scotland?

Eunomia's Response: There was an override in the assumption of 25% of ammonia on Other data D57, it has been brought back to 25%. This represents a 0.2% increase of the balancing item on the input side, which also does not affect the main indicators such as DMC and RMC.

General Comments.

Business intelligence dashboard: this would need to identify the likely 'community of users', as structures and classification of e-MFA do not align easily with specific industries (as opposed to Industrial Sectors).

Plastic Flows: it might be worth looking at examples of material/product studies from the UK Mass Balance programme for this.

Introduction of transport services: I do not think the resources required to do this would justify the benefits.

Full carbon accounting: this would add value, have synergies with the Circular Economy work in Scotland, and be reasonably straightforward.

Eunomia's Response: we have added this to the 2019 report conclusions, section 5.2.

Annex 2: List of revisions made to December 2022 Release

Following feedback received on the original release, Zero Waste Scotland chose to revise and expand on certain elements of the original report in order to clarify our interpretation of the data.

List of revisions:

- Figure 3 has been changed to include RMI and DMC, while DE was removed;
- Content analysing RME trends portrayed in Figure 3 was added or revised;
- All content following Figure 3 regarding the smoothing of RME data has been added;
- Figure 4 and the content below it analysing the smoothed RME data has been added;
- Figure 5 and the following two paragraphs comparing trends in GDP and the material flow indicators has been added;
- Revised versions of Figure 6 and 8 were added;
- Figure 10 and the following paragraph comparing Scotland's RMC to Europe and the UK has been added;
- The statement "Finally Scotland's RMC per capita of 19.3 is higher than EU-28 average of 11.3" has been removed;
- In Section 3.4 Overview of Findings, the bullet point "From 2011 to 2018, real GDP has increased by 8.5% while DMC (tonnes per capita) has decreased almost 15%. This implies a partial decoupling of material requirements for GDP growth; and " was removed;
- Section 3.4 bullet point "Scottish material footprint (DMC per capita) has declined overall since 2011;" rephrased to "Scottish DMC per capita has declined overall since 2011;".

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