ZERO WASTE SCOTLAND

ZERO WASTE SCOTLAND COP26

Scottish Material Flow Accounts
Technical Report

Report written by:
Zero Waste Scotland

Research conducted by:
Eunomia Research & Consulting

External Peer Review by:
Queen's University Belfast

Date: May 2021

European Union
gov.scot

EUROPE & SCOTLAND
European Regional Development Fund
Investing in a Smart, Sustainable and Inclusive Future

List of abbreviations and acronyms

BGS	British Geological Survey
CO_2e	Carbon Dioxide equivalent units
CN code	Combined nomenclature code
COMEXT	Eurostat online database for external trade
DE	Domestic extraction
DMC	Domestic material consumption
DMI	Direct material input
DPO	Domestic processed output
EEA	European economic area countries
E-PRTR	European pollutant release and transfer register
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
GWP	Global warming potential
HMT	Her Majesty's treasury
I-O table	Input-output table
MFA	Material flow accounts
NAEI	National atmospheric emissions inventory
ONS	Office of National Statistics
PRODCOM	PRODuction COMmunataire (EU community survey of industrial production)
PTB	Physical trade balance
RAG	Red Amber Green
RMC	Raw material consumption
RME	Raw material equivalents
RMI	Raw material input
UK	United Kingdom
WFAS	Waste from all sources

Contents

Project details, disclaimer and copyright

Project name: Scottish Material Flow Accounts – Technical Report

Written by: Michael Lenaghan and Kimberley Pratt, Zero Waste Scotland

Research conducted by: Tanzir Chowdhury, Daniel Card, Sean Hollowed, Amy Nicholass and Tim Elliott, Emiliano Lewis and Lucy Eggleston, Eunomia Research and Consulting

External Peer Review by: Dr Robin Curry, Queen's University Belfast

Research date: January 2019 – March 2021

Publication date: May 2021

Disclaimer

Whilst reasonable steps have been taken by Zero Waste Scotland to produce this report and ensure that the content and information contained in this document is correct in all material respects, such content and information may be incomplete, inaccurate and/or out of date. Accordingly, reliance should not be placed on this document by the Recipient (or any other person) and the Recipient is recommended to seek its own advice in connection with the purposes for which it intends to use the report. Zero Waste Scotland does not accept liability for any loss, damage, cost or expense incurred or arising from reliance on this report.

References made to specific information, methods, models, data, databases, or tools do not imply endorsement by Zero Waste Scotland.

Executive Summary

The Scottish Material Flow Accounts study describes the flow of materials in and out of the Scottish economy in detail for the first time. The Scottish MFA aim is to inform, influence and evaluate progress towards more sustainable consumption in Scotland.

As part of the Scottish Government's commitment to transition Scotland towards a more circular economy, it is essential to improve our understanding of material flows. The way we consume materials today is unsustainable and contributes to many global environmental and social problems, from climate change and biodiversity loss through to issues of economic inequality. The goal of a circular economy is to use materials as sparingly and efficiently as possible. This can be done by reducing the quantity of materials entering an economy and greater circulation of the materials we do consume before they become waste. The most advanced international MFAs, such as those compiled annually by Eurostat for EU nations, are used to track progress towards resource efficiency goals and policies. The publication of Scotland's first MFA is a vital step on our path towards more sustainable material consumption.

The Scottish MFA approach

The Scottish MFA was developed based on the following flows:

1. **Domestic Extraction** (natural resources extracted from the Scottish environment);
2. **Imports** (of raw materials, finished and semi-manufactured products and potentially waste);
3. **Exports** (of raw materials, finished and semi-manufactured products and potentially waste);
4. **Domestically Processed Outputs** (waste and emissions generated through production and consumption, as well as dissipative[1] uses and losses); and
5. **Balancing Items** on Input and Output Sides (which are needed to establish economy wide material balance, e.g., oxygen used up and water vapour generated in combustion processes).

Besides these direct flows, **indirect flows** which measure upstream materials associated with the import and export of semi-finished and finished goods are also included (e.g. ore mined for metal production and offcut waste from manufacturing) using input coefficients for different production processes. Finally, there is often domestic extraction of materials that remain unused, such as unused extraction from mining and quarrying, the unused parts of forestry and felling and unused by-catch in fishery. These are classified as **hidden flows** (also sometimes known as unused flows) which are estimated using coefficients for biomass and minerals extraction processes. However, hidden flows were not included in the Scottish MFA (as in other published MFAs including the EU MFA), as reliable data to estimate these flows were not available.

MFAs show material flows of traded materials in two ways. Either the mass of the materials traded are quantified or the mass of raw materials required to produce traded materials are quantified. The former is known as **physical flows** and measured with the MFA indicator **Domestic Material Consumption** (DMC). The latter is known as the **Raw Material Equivalents** (RME) and measured with the indicator **Raw Material Consumption** (RMC). The Scottish MFA includes estimates of both physical flows and raw material equivalents as both are useful indicators for understanding Scotland's material impacts. Box 1 overleaf describes the key terms used throughout the Scottish MFA study.

[1] Dissipative uses of products and dissipative losses are defined as materials which are dispersed into the environment as a deliberate or unavoidable consequence of product use e.g. fertiliser use, tyre abrasion.

Box 1. Key terms for Scottish Material Flow Accounts

Decoupling A trend where two variables which previously aligned, separate. Of most interest for the Scottish MFA, is whether material consumption can decrease relative to population size, and GDP.

Domestic Extraction (DE) The raw materials from the national natural environment, such as fish, oil and stone, which are inputted into the same economy.

Domestic Material Consumption (DMC) The mass of material used in an economy, adding imports, and subtracting exports, based on the physical mass of the materials traded. The mass of raw material required to produce traded materials are not included.

Domestic Material Inputs (DMI) The mass of materials which enter the economy including domestically extracted and imported material.

Intra-UK trade Transaction of materials to and from Scotland with all other UK economies. This is embedded in the Scottish MFA model separately from trade with the rest of the world. As most of Scottish trade is with the rest of the UK, this extra level of detail is required to ensure the accuracy of the model.

Material footprint The average tonnes of materials, including raw material requirements for traded materials, used per person per year in an economy. This is the Raw Material Consumption (RMC) per capita. It is a similar concept to a carbon footprint for a nation, which shows greenhouse gas emissions per person.

Physical flows The mass of materials imported and exported to and from an economy based on the mass of the materials being traded. It excludes the raw materials required to produce traded materials.

Raw Material Consumption (RMC) The mass of material used in an economy adding imports, and subtracting exports, including the raw materials extracted to produce the traded materials. The asymmetry between domestic extraction and physical trade means a country could significantly reduce its DMC without reducing worldwide demand for material resources. RMC allows for a more complete measurement of material consumption.

Raw Material Equivalents (RME) Factors used to estimate the raw material extraction requirements for all traded materials and products. The Scottish MFA uses RME factors developed by the EU.

MFA Outputs

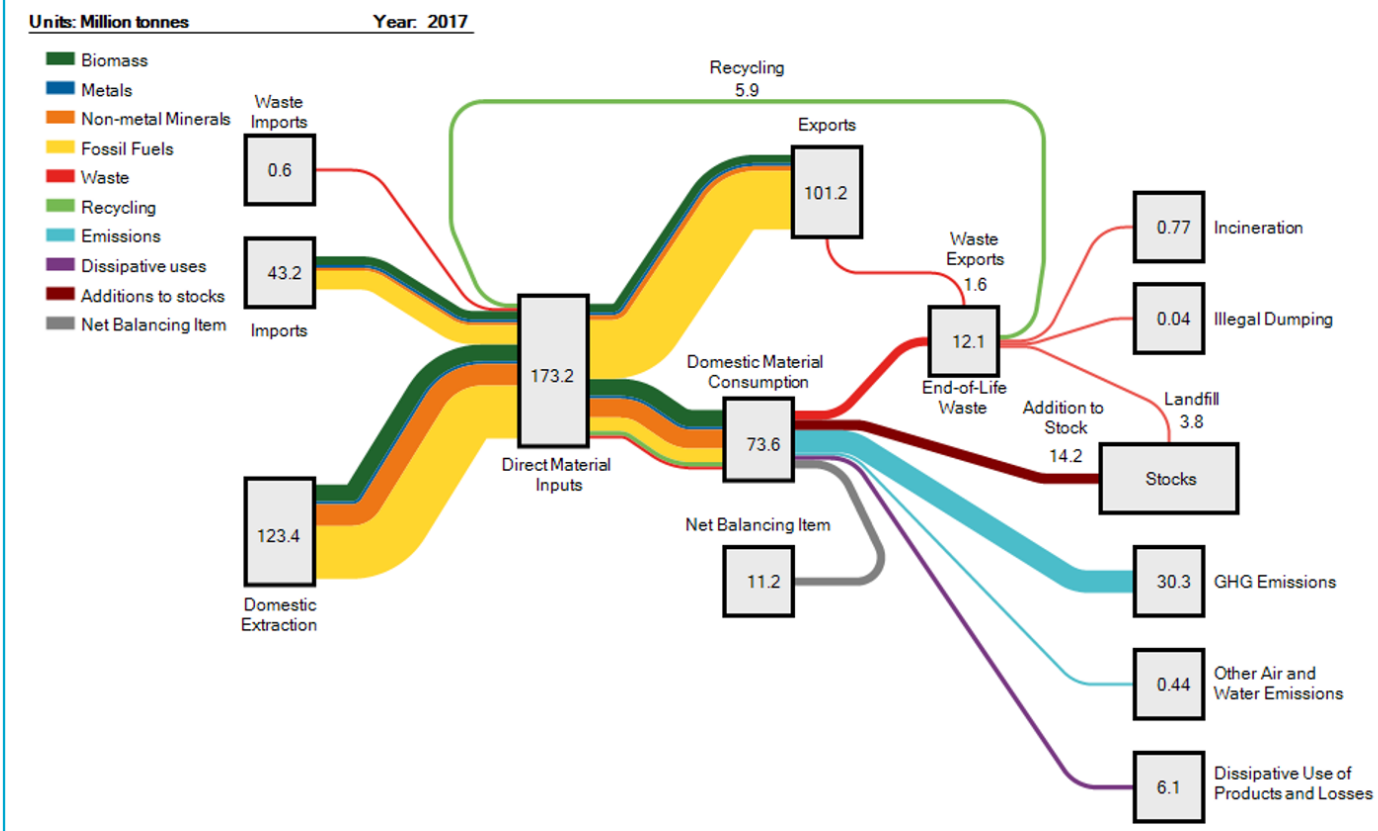
The results of the Scottish MFA are presented using a set of indicators commonly used in MFA reporting, including **Domestic Extraction, Domestic Material Consumption (DMC)** and **Raw Material Consumption (RMC)**. These indicators show how materials are flowing through the economy. Examples of questions that can be explored through the Scottish MFA dataset include:

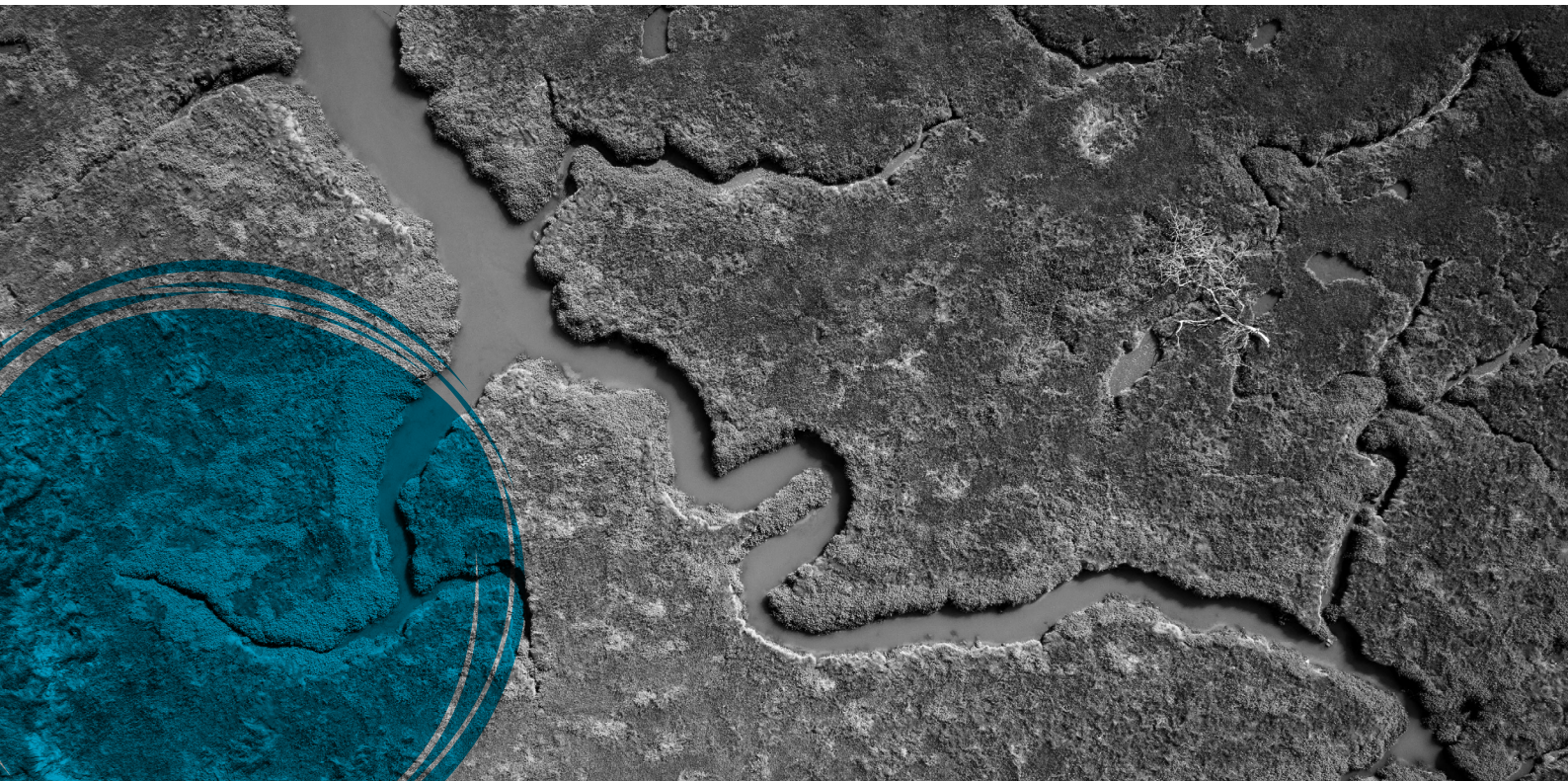
- What is the relationship between domestically extracted and imported materials in an economy?
- What type of materials is an economy importing or exporting?
- How significant are the raw material requirements for imports and exports?
- How much of what we are consuming remains in an economy and what becomes waste or emissions?

Figures E-1 shows the material flowing in and out of the Scottish economy in 2017. Some of the indicators (e.g. DMI and DMC) in the Sankey diagrams differ from those in the rest of the report. This is because waste flows have been added to the Sankey to show the relevance of these flows against material inputs. The MFA indicators in the rest of the report align with the EU MFA definitions of these indicators.

The results of the Scottish MFA should be interpreted with caution due to various data and methodological limitations.

Figure E-1 Physical material flows in Scotland in 2017, millions of tonnes





The main findings of the Scottish MFA are:

Scottish material flows in 2017

- Scotland's Domestic Material Consumption (DMC)[2] was 66 Mt of materials, or 12.2 tonnes per capita;
- Scotland's Raw Material Consumption (RMC)[3] was 100 Mt of materials, or 18.4 tonnes per person. This is 38% higher than the global average, which is 13.3 tonnes per person and more than twice as high as the level many experts suggest is sustainable (8 tonnes per person per year)[4];
- 123 Mt of materials were extracted from Scotland's natural environment, of which 58% were fossil fuels, 24% were non-metallic minerals and 18% was biomass. No metals were extracted domestically;
- Scotland is a net exporter of materials. 79% of physical material exports are fossil fuels;
- If the raw material requirements of imports are included, the mass of imports (129 Mt) exceeds that of domestic extracted materials (123 Mt) and exports (101 Mt);
- 12 Mt of material became waste in Scotland in 2017, of which 49% (6 Mt) was recycled.

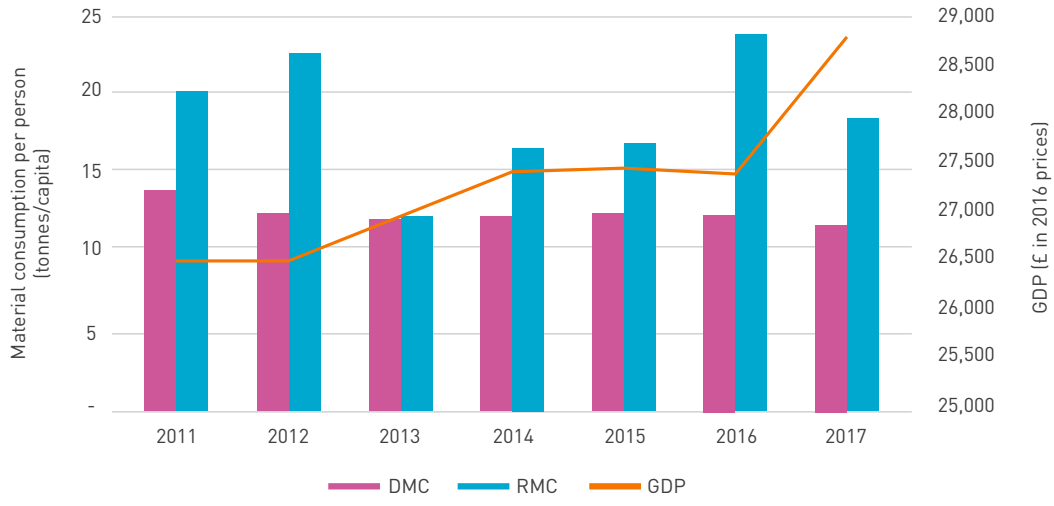
Trends in material flows 2011-17

- Scotland's Domestic Material Consumption decreased by 10% from 2011-17. The Raw Material Consumption shows considerable variation over the same period, with no clear trend.
- Real GDP increased 11% over this period, implying the material intensity of Scotland's economy is declining, a process known as 'decoupling'. (see Figure E-2 below).

Comparisons to other nations[5]

- Scotland displayed higher levels of Domestic Extraction than the EU-28 average and the UK as a whole (Figure E-3). This is largely due to high levels of fossil fuel extraction, most of which is exported (Figure E-4).
- Scottish Domestic Material Consumption is similar to the EU average but rises above average when raw material requirements are included (Figure E-4)
- Scotland's Domestic Material Consumption per capita is 44% larger than the UK as a whole (Figure E-4). A regression analysis showed that the difference is linked to population and climate. Scotland's lower population density means more materials are required per person for civic amenities including roads, bridges and public buildings. The colder climate means there is more demand for heating fuels.

Figure E-2 Material consumption and GDP trends in Scotland 2011-17



[2] This is the mass of materials consumed. Only the physical weight of traded goods are included. [3] This is the mass of materials consumed, including raw material requirements of traded goods. [4] For example, Lettenmeier et al. (2014) Eight Tons of Material Footprint—Suggestion for a Resource Cap for Household Consumption in Finland. [5] The methodologies of the Scottish MFA and the UK and EU MFAs differ regarding trade data. The Scottish model includes an additional layer of modelling to ensure intra-UK trade is considered, a step that UK and EU MFAs do not require. This creates an element of uncertainty in comparisons to these MFAs which must be considered with any interpretation of the results.

Figure E-3 Per capita Domestic Extraction for Scotland, the UK and European nations, 2017

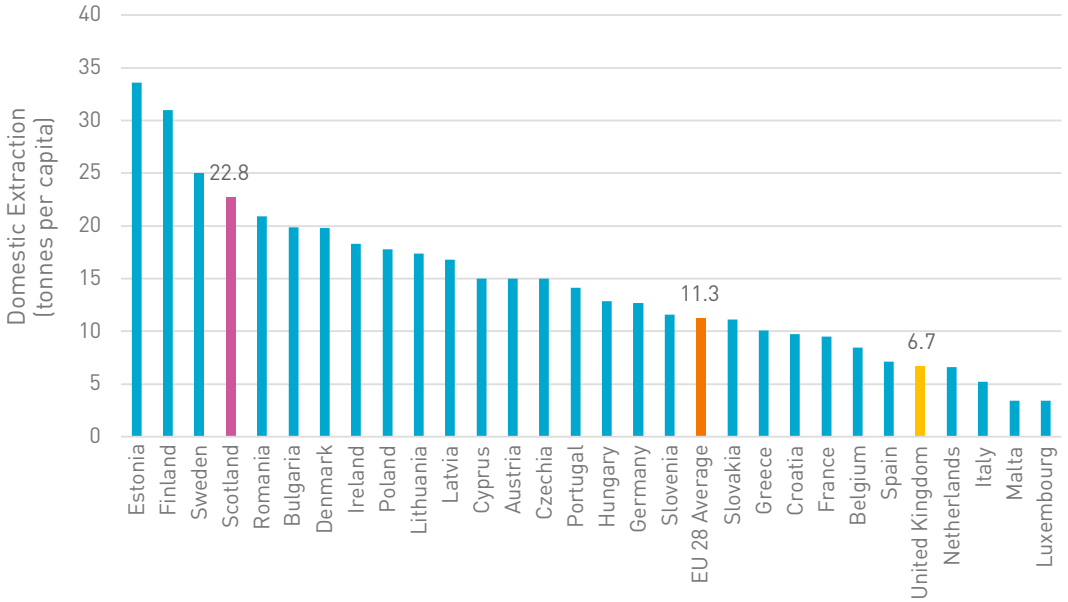


Figure E-4 Comparison of material flow indicators for EU-28 average, UK and Scotland, 2017

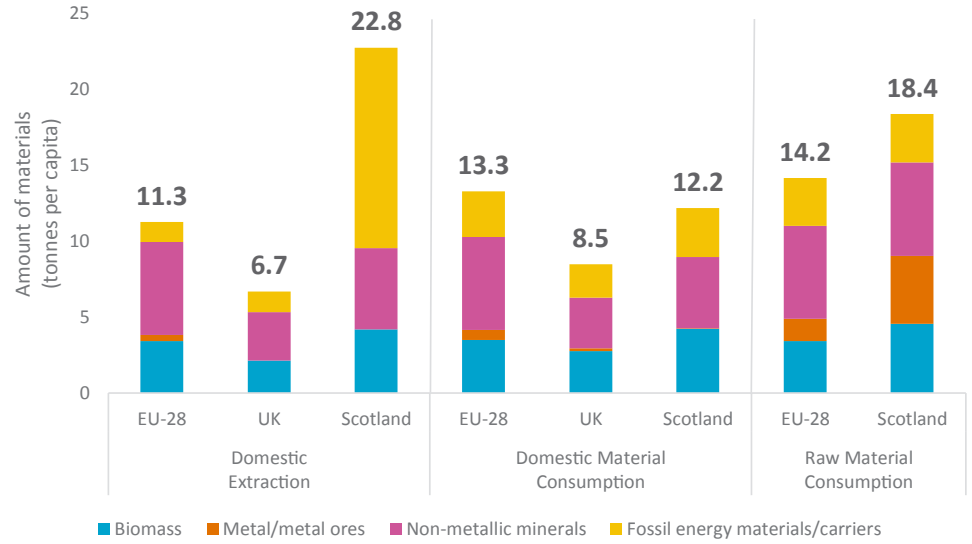
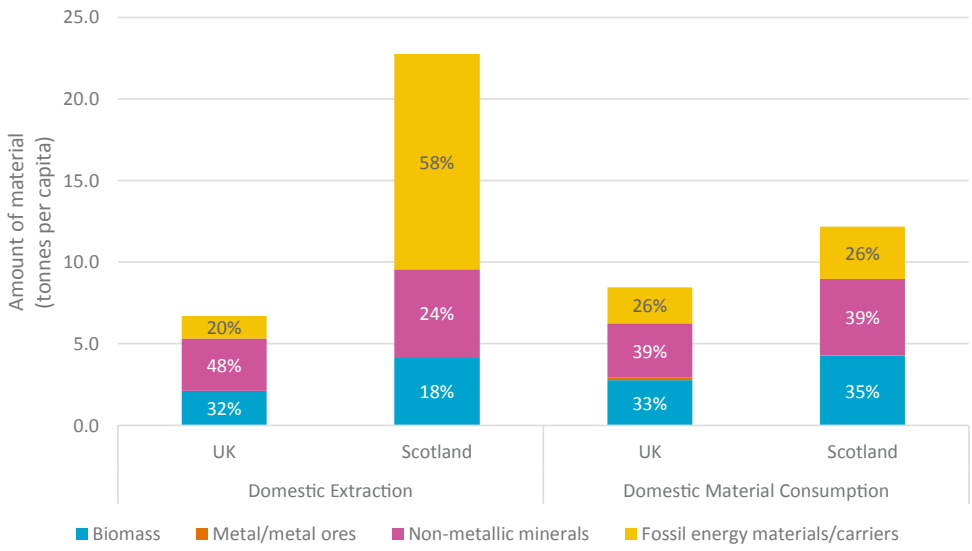


Figure E-5 Comparison of material indicators for UK and Scotland, 2017



Implications of publishing Scotland's first MFA

This study has developed the first economy-wide overview of Scotland's material flows. It will increase understanding of material consumption in Scotland which will help to prioritise areas for change and ways to reduce environmental impacts. Developing the Material Flow Accounts, particularly in conjunction with existing tools, such as the Scottish Government's annual Carbon Footprint publication and Zero Waste Scotland's Carbon Metric, will support the transition to a circular economy.

Study limitations and improvements

As with any model, there are areas of uncertainty due to imperfect information. The greatest data gap is the lack of Scottish trade data by mass. This is estimated in the model using imports and export volume data for the UK reported to Eurostat and scaled to Scotland using the Scottish and UK Input-Output financial tables. It is not possible to estimate the scale of this uncertainty on the results. This data gap, and other limitations with the data and model, means that caution should be used in interpreting the Scottish MFA results, particularly around trade[6].

An independent peer review was conducted on the Scottish MFA and found that the data sources and methodology were appropriate and robust.

It is expected that this first attempt at a Material Flow Accounts for Scotland will be improved on over time. The model has been designed to be updated regularly as new data becomes available. As the Scottish MFA is further developed, its ability to monitor and measure Scotland's transition to a circular economy will improve. Priorities for improvements include:

- Collect data on Scottish trade in mass;
- Incorporate UK level data on hidden flows (domestic extraction of unused materials, such as mining overburden) for Scotland;
- Add intra-economic material flows (e.g. fuel consumed by transport, biomass as food etc.);
- Apply carbon factors to the material flows. This would be an ambitious but useful development. It would frame Scotland's greenhouse gas emissions in a new way, highlighting which materials need to be prioritised to minimise our climate change impacts.

This study has created a new set of indicators for Scotland and the outputs are expected to inform policy decision making on sustainable material consumption for many years to come.

Other outputs of the Scottish MFA

This technical report explains the development, methodology and results of the Scottish MFA in detail. It also includes a summary of the independent peer review and response. An Excel version of the main model is available on the Zero Waste Scotland website[7] to allow others to access and explore the dataset. The supplementary model on trade is available on request.

[6] With the exception of fossil fuel trade which is measured and reported on directly by Scottish government and is therefore considered more reliable.

[7] www.zerowastescotland.org.uk/mfa

1 Introduction

Background

As part of the Scottish Government's commitment to transition Scotland towards a more circular economy, it is essential to improve our understanding of material consumption. Along with many developed nations, Scotland's consumption of materials is unsustainable and incompatible with our environmental and social goals, particularly those concerning climate change and social justice. If we are to reduce the impact of our material consumption effectively, we must have a good understanding of how materials are flowing through our economy. The goal of a circular economy is to use resources as sparingly and efficiently as possible. By prolonging the useful life of products and materials already within the economy, we can reduce the amount of new material inputs, and waste outputs. The Scottish MFA will give us the overview we need of how materials are flowing through our economy, to prioritise the changes required.

Material flow accounting is an approach to measuring material flows in and out of the economy. It can be used to inform, influence and evaluate progress towards a more sustainable resource use. Numerous national and regional governments have produced Material Flow Accounts (MFAs) of varying detail and frequency, using a variety of methods. Examples include:

- The UK (ONS, 2000-present)[8]
- Japan (Ministry of Environment 2006)[9]
- Eurostat (2008-present)[10]
- Denmark (Statistics Denmark, 1993-2017)[11]

The most developed MFAs, such as the EU MFAs, are used to track progress towards resource efficiency goals and policy at national and international level. There are several online databases which cover national or international material, energy, water and land flow accounts[12].

The EU Monitoring Framework for a Circular Economy[13], Raw Materials Scoreboard[14] and Resource Efficiency Scoreboard[15] draw data from Eurostat material flow accounting data and provide consistent national level information for all Member States. These tools are used to map the material intensity of sectors or nations, track reliance on raw material imports, measure progress towards resource efficiency.

Developing an MFA at a Scottish level comes with particular challenges; while Scotland possesses a considerable collection of datasets, it lacks key data on trade flows as these are typically produced at a UK level. A combination of Scottish and UK trade datasets have been used to address this in this study.

This study has developed the first detailed and complete Material Flow Accounts model for Scotland. It brings together publicly available datasets, using best practice from international MFAs, to describe the flow of materials in and out of the Scottish economy for 2011-17. This initial model will be built upon and improved over time as new data sources become available and methods are updated.

Data requirements

Developing a comprehensive MFA at a Scottish level required an approach which brought together several separately developed data sources on material flows. Reliable Scottish data was used where available. Nearly all domestic extraction data was from Scottish-level sources (Table 3-2 gives a more detailed description of the data sources for different parts of the Scottish MFA model). Financial and/or non-Scottish data was used to fill gaps only where needed.

[8] ONS (2020) Material Flow Accounts. [9] Ministry of the Environment, Government of Japan (2006) Material Flow in Japan. [10] Eurostat (2020) Material flows and resource productivity. [11] Denmark statistics (2020) Economy-wide material flow accounts. [12] For example, Eurostat (2014) Physical Water Flow Accounts. [13] Eurostat Monitoring Framework for a Circular Economy. [14] Eurostat (2018) Raw Materials Scoreboard. [15] Eurostat (2019) Resource Efficiency Scoreboard.

Where source data was converted for use in the Scottish MFA (see Annex 1 for further details), this process has been clearly documented. The choice to convert certain data has also been justified, and assumptions made clear, with the output evaluated for quality. Remaining data gaps or uncertainties have been clearly identified, to allow continual improvement of the methodology in future. All data entries within the Scottish MFA have been catalogued to allow for easy and timely updates. As with other MFAs, materials have been grouped into four primary categories while maintaining a practical level of resolution. Final material flows have been presented for the four primary categories and relevant sub-categories[16].

This report describes the Scottish MFA methodology and results in detail. It also includes a statement from an independent peer reviewer and response (Annex 2). This peer review was conducted to ensure the quality of the Scottish MFA and give decision makers confidence in the results. Further outputs from this study, including an Excel version of the main model, are available on the Zero Waste Scotland website[17].

[16] The sub-categories included in the final material flows are in line with the EU-MFA sub-categories, which are higher than the number of sub-categories included in the UK-MFA. [17] www.zerowastescotland.org.uk/mfa

2 The Scottish Material Flow Accounts approach

2.1 Overview

A Material Flow Accounts (MFA) balances the mass of material inputs into an economy, with the accumulation of material capital, and outputs from the economy. Material inputs into the economy include domestic extraction of material from the environment and physical imports from other economies. This material either accumulates in the economy as stocks (e.g. infrastructure, long-life goods) or becomes an output such as a physical export to another country, waste, or emissions to air and water.

2.2 Key Material Flows

The two types of direct input flows for materials are:

- **Domestic Extraction**
- **Imports**

Materials either accumulate in the economy (known as material accumulation or stocks) or become one of two types of direct output flow:

- **Exports**
- **Domestically Processed Output (e.g. emissions to air and water)**

A simplified MFA framework is presented in Figure 2-1, which depicts the direct input and output flows.

Balancing items, such as oxygen and water used during combustion, are also quantified as these are essential to maintaining mass balance.

Besides these direct flows, there are **indirect flows** and **hidden flows**. All the above flows are described in detail below.

Domestic Extraction

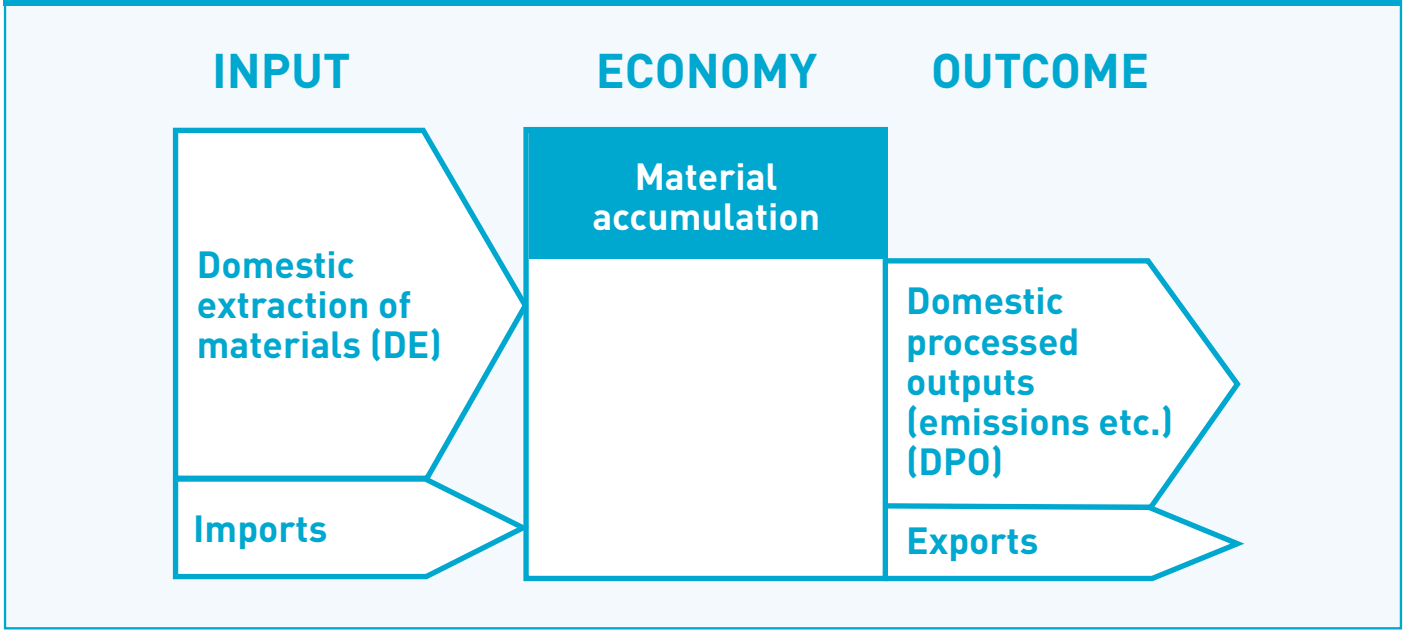
This includes the extraction of natural resources from the domestic environment. Domestic extraction is categorised into four groups in most MFAs, including the Scottish, UK and EU-MFAs. These categories are:

1. **Biomass** which comprises agriculture harvest, timber, animal grazing, and fishing;
2. **Metal ores** which includes ferrous and non-ferrous metals;
3. **Non-metallic minerals** which includes constructions aggregates, limestones, and clays; and
4. **Fossil energy materials/carriers** which comprises of coal, natural gas and crude oil.

Imports and Exports

Both imports and exports include raw materials, as well as semi-manufactured and finished products and potentially wastes.

Figure 2-1 Simplified Material Flow Account Framework[18]



[18] Eurostat (2020) Material Flows and Resource Productivity.

Domestically Processed Outputs (DPO)
Consumption of materials by people in Scotland and waste generated through production and use of goods and services needs to be included in the Scottish Material Flow Accounts. This includes:

- Direct emissions to air and water;
- Dissipative use of products (where materials are dispersed into the environment through their use) e.g. fertiliser application; and
- Dissipative losses e.g. emissions to air from automobile tyre; and brake wear and road abrasion, are also added to the DPO.

The scale of water use is so significant that including its mass in MFAs obscures other resource use. For this reason, standard MFA practice is to only include water mass contained in products e.g. agricultural produce and imported beverages. Water for other consumptive uses (cleaning or irrigation) and in situ uses (such as hydroelectric power), sometimes known as bulk water in MFAs, will be excluded from these accounts.

Balancing Items and Material Accumulation
The input and output sides of the MFA are balanced to ensure all materials flowing into an economy in one year are accounted for. Balancing items on the input side mainly include oxygen requirements for combustion processes and respiration, nitrogen for production of ammonia, and water requirements for the domestic production of exported beverages. Balancing items on the output side mainly include water vapour generated from combustion process, gases from respiration and evaporated water from biomass products.

After adding the balancing items to input and output flows, the remaining materials are classified as material accumulation. This includes materials which are retained within the economy in the form of buildings, infrastructure and longer life products (e.g. furniture, electronics). Landfilled waste is also considered a stock since the material is permanently stored.

Indirect Flows and Hidden Flows
Indirect flows measure the upstream quantity of materials associated with the imports of semi-finished and finished goods into the economy and are needed to estimate the raw material requirements of traded materials in an MFA. For example, to produce a tonne of imported canned fish, the upstream raw material requirements are the fish, metal cans, and the fossil fuel energy used to produce the canned fish. As these upstream raw material requirements are not exactly known, they are estimated based on input coefficients for different production processes. These coefficients are averaged factors for various inputs. Similar indirect flows can be defined for exports of semi-finished and finished products.

The domestic extraction of materials that remain unused are classified as hidden flows (which are not included in the Scottish MFA). Examples of hidden flows are unused extraction from mining and quarrying (also known as overburden), discarded material from harvesting (e.g. wood harvesting losses), and soil and rock moved as a result of construction and dredging. Like indirect flows, these are also estimated using coefficients for biomass and minerals extraction processes.

Indirect flows and hidden flows associated with imports and exports are more difficult to establish than direct flows. Where possible, these are estimated using a set of default coefficients corresponding to each imported or extracted material. These coefficients are published by the Wuppertal Institute[19], and they are used in most MFAs, including the EU-MFA.

[19] Wupperinst Institut https://wupperinst.org/en/

2.3 Indicators

The main results of the MFA shows the various direct, indirect and hidden flows within the economy. MFA results are also commonly presented as a set of six indicators that measure the resource burden for the economy (see Table 2-1 and Figure 2-2).

Figure 2-2 illustrates the relationships between different indicators discussed above.

Table 2-1 Description of main MFA indicators

1) Direct Material Inputs (DMI) = domestic extraction + imports
The mass of all materials that enter the economy for further use, either in production or consumption processes. These include domestically sourced materials (including hidden flows, if known) and imported materials and products.

2) Domestic Material Consumption (DMC) = DMI – exports
Material directly used in an economy through domestic final demand (and which become stocks, waste or emissions).

3) Physical Trade Balance (PTB) = imports – exports
Economy has a trade deficit if imports > exports, and a trade surplus if imports < exports.

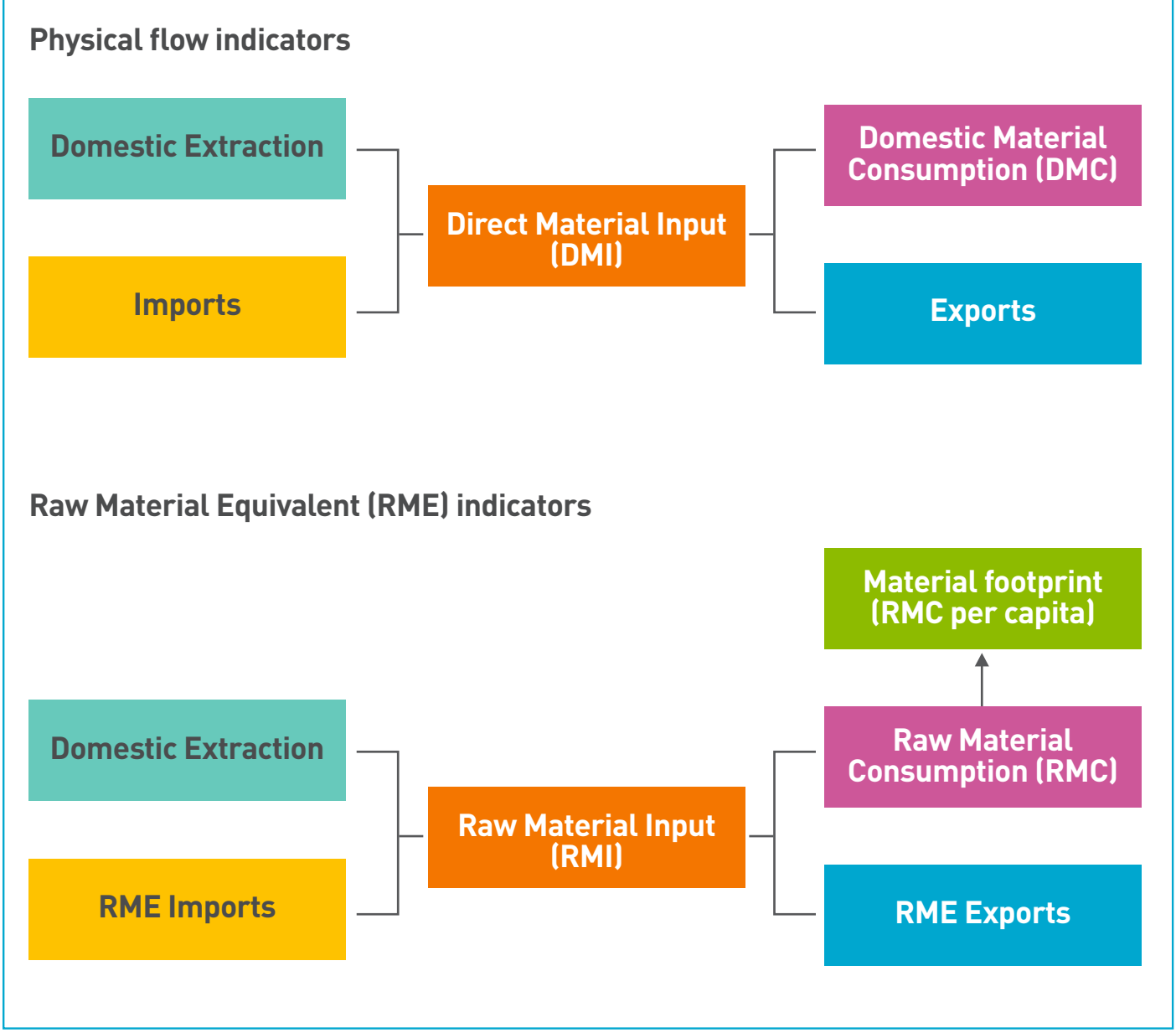
4) Raw Material Input (RMI) = domestic extraction + imports + indirect flows associated with imports
Total material requirements of the economy.

5) Raw Material Consumption (RMC) = RMI – (exports + indirect flows associated with exports)
Total materials required to satisfy domestic consumption.

6) Material Footprint = RMC / population
Raw material consumption per person within an economy[20].

[20] This is calculated using mid-year population estimates.

Figure 2-2 Relationships between MFA Indicatorstonnes



These MFA indicators can be compared to other indicators related to the economy, as well as to each other. For example, resource productivity is a measure of the total amount of materials used by an economy in relation to GDP. Trends in resource productivity can be shown once MFA indicators have been established.

If material consumption reduces compared to GDP, this is known as decoupling. Decoupling may indicate the possibility of environmental sustainability without economic loss. MFA indicators can be used to show whether decoupling is happening at a national scale for Scotland.

3 Methodology for model development

This section describes the method used to develop the Scottish MFA. This was done in four stages:

1. A desk-based review of existing MFAs;
2. Gathering the required data sources, assessing these for suitability and ensuring there were no gaps in the model;
3. Developing the model so that all data sources were integrated correctly, and the results presented in a useful manner; and
4. External peer review of the process to ensure quality.

These stages are described below in more detail.

3.1 Review of existing MFAs

A desk-based review of existing MFAs, best practice approaches to MFA development and their use was conducted. The following examples were reviewed:

- EU (Eurostat, 2008-present)[21]
- UK (ONS, 1990-present)[22]
- Denmark (Statistics Denmark, 1993-2017)[23]
- Finland (Statistics Finland, 1970-2018)[24]
- Japan (Ministry of Environment, 2006)[25]
- The United States of America (WRI, 2008)[26]

European nation states are required to report statistics on the production of manufactured goods annually (known as ProdCom[27]). This detailed database gives consistency to EU nation MFAs, allowing great comparability. The EU-MFA Questionnaire[28] and guidance is a fully functioning template for conducting MFAs. The EU-MFAs do not include indirect flows, hidden flows, stock and net additions and subtractions. Some nation states, such as Finland, have built on their EU-MFAs, including these elements and using more detailed national data where possible.

The UK has a long running MFA dataset, published by ONS since 1990, which present major material flows at an aggregate level. The US-MFA uses a different, estimation-based, approach to most MFAs. It does not always match observable data but is still used to support decision making for key industrial sectors in the US economy. The Japan MFA, conducted in 2006, focused on a limited set of materials.

The Scottish MFA is based on the EU-MFA approach, utilising the most reliable existing data sources and allowing consistency and comparability with EU nations, at least for as long as the UK reports to the ProdCom database. In a similar approach to that developed by Finland and Denmark (some of the most sophisticated and detailed MFAs published to date) the Scottish MFA has extended the EU-MFA model. Indirect flows, stocks and net additions and subtractions are included (although, hidden flows were excluded at this time as data, thus far, remains insufficient). The EU Raw Material Equivalents (RME) tool and Scottish specific datasets were used to do this.

3.2 Analysis of best available material data

The development of the Scottish MFA required data on extraction, imports and exports expressed in physical quantities or mass. Various data sources were explored, with preference given to Scottish specific datasets. These were available for domestic extraction, waste and emissions from the Scottish Government, SEPA, ONS and various other official sources. Except for fossil fuels, physical quantities data on trade for Scotland were not available. So, for these flows, UK level physical quantities data was used and scaled to Scotland using financial coefficients.

The material categories that were included in the Scottish MFA model are based on the EU-MFA. Annex 1 describes the methodological approach in detail. The data sources, assumptions and calculations used to construct different material flows and indicators in the Scottish MFA model are explained.

The collected data was catalogued, categorised in an MS-Excel template and data quality evaluated

[21] Eurostat (2020) Material flows and resource productivity. [22] ONS (2020) Material Flow Accounts. [23] Denmark statistics (2020) Economy-wide material flow accounts. [24] Finland statistics (2018) Economy-wide material flow accounts. [25] Ministry of the Environment, Government of Japan (2006) Material Flow in Japan. [26] World Resources Institute (2008) A Physical Accounting of the US Industrial Economy. [27] Eurostat ProdCom Overview. [28] Eurostat MFA Questionnaire

using 'Red, Amber, Green' (RAG) scoring method. This RAG status classifications are presented in Table 3-1 below.

Table 3-2 below summarises the main data sources used.

Table 3-1 RAG Status Classifications

●	Reliable data that is up to date - annually updated Scottish data
●	Potential inaccuracies - UK data scaled to Scotland or Scottish data not updated annually
●	Likely inaccuracies - all other data

Table 3-2 Summary of the main data sources used in the Scottish MFA

Data requirement	Source	RAG status
Domestic extraction, biomass: crops	Scottish Government, Economic Report on Scottish Agriculture	●
Domestic extraction, biomass: crop residues	Scottish Government, Economic Report on Scottish Agriculture	●
Domestic extraction, biomass: wood	Forestry Commission, Wood production (Scotland)	●
Domestic extraction, biomass: fish	Scottish Government, Scottish Sea Fisheries Statistics and Scottish fish farm production survey	●
Domestic extraction, biomass: live animals	Scottish Government, June Scottish Agricultural Census	●
Domestic extraction, non-metallic minerals	British Geological Survey: UK Minerals Yearbook 2018	●
Domestic extraction, fossil fuels	Scottish Government, Oil and Gas Commodity Balances	●
Imports and exports	Eurostat COMEXT data on goods and products for the volume of goods traded with the UK and Scottish and UK Input-Output tables for scaling this data to Scotland	●
Raw material equivalents of imports and exports	EU RME model	●
Exports and RME exports of rock	UK Department of Transport, Port freight annual statistics for Glensanda quarry	●
Emissions to air	National Atmospheric Emissions Inventory - Devolved Administration Data	●
Emissions to water	EU E-PRTR	●
Waste	SEPA - Waste from All Sources	●
Dissipative use of products and dissipative losses	Mineral fertiliser: Economic Report on Scottish Agriculture	●

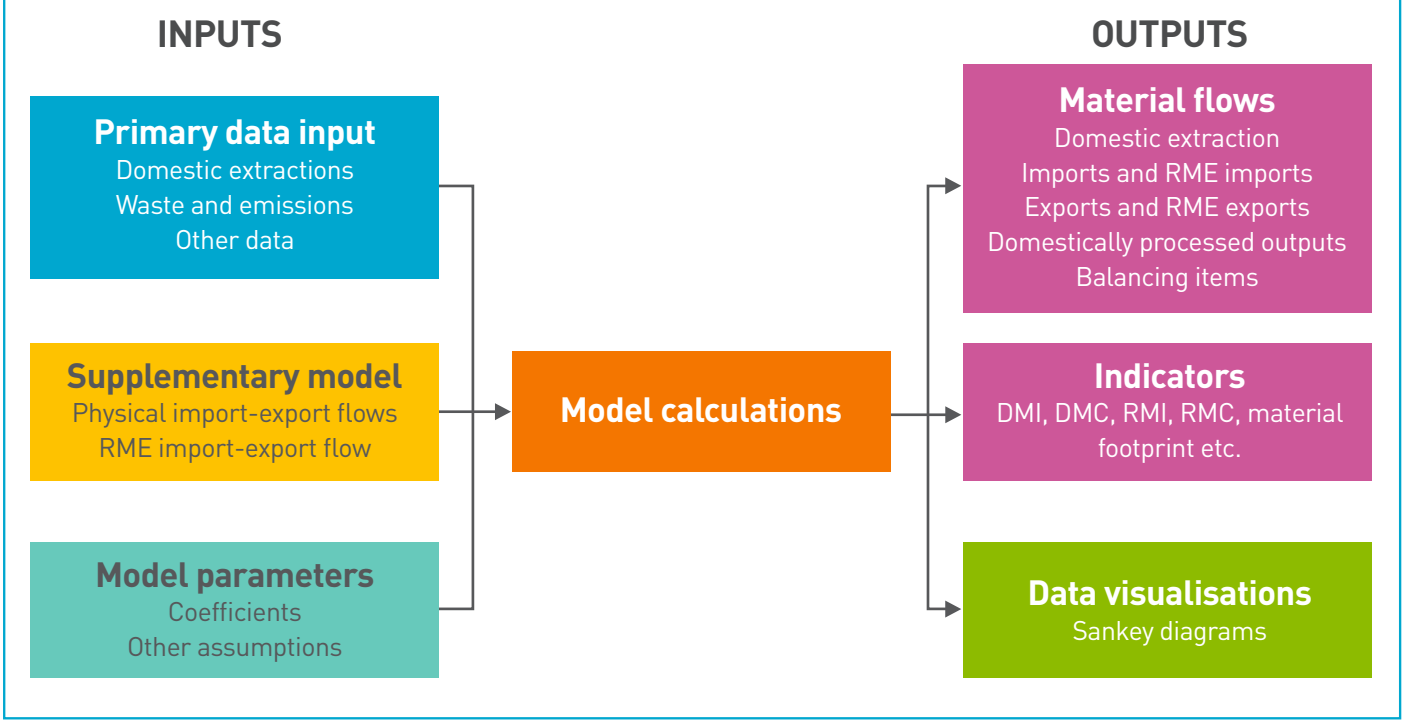
3.3 Development of the Scottish MFA Model

The Scottish MFA model was developed in MS-Excel and has three main types of sheets:

- Inputs;
- Calculations; and
- Outputs.

The material categories were selected based on the EU-MFA material categories. The high-level model structure is depicted in Figure 3-1.

Figure 3-1 Scottish MFA Model Structure



The main elements of the input sheets are Scotland specific primary data on domestic extraction of biomass, minerals and fossil fuels, waste flows, emissions, and other relevant data such as, GDP, population and fuel bunkered.

The data for physical and RME imports-exports are generated in a separate supplementary model (due to the size of the datasets). Physical imports and exports for Scotland are estimated using Eurostat's ComExt trade data for the UK due to the absence of Scotland specific data on physical imports and exports[29]. UK data is scaled down to represent Scotland using the ratio of Scotland and UK trade data for different sectors from the financial Input-Output tables for Scotland and the UK. The supplementary model also estimate RME imports and exports for Scotland using RME coefficients from the EU RME-tool. Both physical and RME imports-exports are disaggregated by separating between trade with the rest of the UK and trade with the rest of the world.

Data from primary data input sheets and the import-export data from the supplementary model are combined with required parameters to estimate the material flows for domestic extraction, DPO and balancing items. These outputs are groups in the model under the title "Material Flows".

The second set of output sheets (grouped together in the model as "output" sheets) calculate the key additional indicators, such as Direct Material Inputs (DMI), Domestic Material Consumption (DMC), Physical Trade Balance (PTB), etc. using the material flows in the Material Flow output sheets. These outputs present the data visualisations using Sankey diagrams.

Further details on data sources, model parameters and modelling assumptions can be found in Annex 1. The main Scottish MFA model is also available on the Zero Waste Scotland website[30], the supplementary model is available on request.

3.4 External Peer Review

An external peer review was conducted of the Scottish MFA by Queen's University Belfast in December 2020. The aim of this review was to establish the quality of the Scottish MFA data and model. The main conclusions of the peer review were that: "The most up-to-date and appropriate datasets have been used in the model" and "there are no changes required to the Scottish MFA model". A full list of the peer review findings are available in Annex 2.

[29] There was one exception to this method: rock export. Initial analysis of the Scottish MFA results showed that rock exported based on UK scaled financial data were underestimating Scottish rock export considerably due to the presence of Glensanda super quarry on the West coast of Scotland. This was corrected with additional data on port freight statistics from Glensanda. A full description of this change to the standard approach is given in the Annex 1. [30] www.zerowastescotland.org.uk/mfa

4 Outputs

In this section, the outputs of the Scottish MFA for 2011-17 are described. It is split into five sections:

- The Scottish MFA in 2017, key indicators;
- The Scottish MFA in 2017, Sankey diagrams;
- Trends in Scottish material flows for 2011-17;
- Comparisons to other MFAs; and
- A summary of the findings.

4.1 The Scottish MFA in 2017, key indicators

Table 4-1 shows the key indicators for the Scottish Material Flow Accounts in 2017, the latest year for which data is currently available. 123.4 million tonnes of materials were extracted from Scotland's natural environment and inputted into the economy in 2017.

For both physical flows and raw material flows of materials, Scotland was a net exporter in 2017. Using raw material flows, Scotland imported more material than is extracted domestically.

The average person in Scotland consumed 18.4t of materials in 2017.

These high-level indicators can be broken down into sub-material categories. Table 4-2 shows the sub-material categories for the key indicators of the Scottish MFA for 2017.

Table 4-1 Key indicators of the Scottish Material Flow Accounts in 2017

Key Indicator	Amount of material (Millions of tonnes)	Amount of material (Tonnes per person)
Domestic Extraction	123.4	22.8
Imports	43.8	8.1
Exports	101.24	18.6
Direct Material Inputs (DMI)	167.3	30.8
Domestic Material Consumption (DMC)	66.1	12.2
RME imports	128.6	23.7
RME exports	152.3	28.1
Raw Material Inputs (RMI)	252.1	46.5
Raw Material Consumption (RMC)	99.8	18.4

Table 4-2 Scottish Material Flow Accounts in 2017, by sub-category		
Key Indicator	**Material flows (Millions of tonnes)**	**Material flows (% of category)**
Domestic Extraction	**123.4**	**100%**
Biomass	22.7	18%
Metal Ore	0	0%
Non-metallic minerals	29.1	24%
Fossil energy materials/carries	71.6	58%
Imports (physical flows)	**43.8**	**100%**
Biomass	11.8	27%
Metal Ore	2.8	6%
Non-metallic minerals	3.2	7%
Fossil energy materials/carries	26.1	60%
Exports (physical flows)	**101.2**	**100%**
Biomass	11.5	11%
Metal Ore	2.6	3%
Non-metallic minerals	6.8	7%
Fossil energy materials/carries	80.3	79%
Direct Material Inputs (DMI)	**167.3**	**100%**
Biomass	34.5	21%
Metal Ore	2.8	2%
Non-metallic minerals	32.3	19%
Fossil energy materials/carries	97.7	58%
Domestic Material Consumption (DMC)	**66.1**	**100%**
Biomass	23.0	35%
Metal Ore	0.2	0%
Non-metallic minerals	25.5	39%
Fossil energy materials/carries	17.5	26%

For most materials, dis-aggregated data exists beyond this level of sub-categorisation, although the quality is variable. A priority for improving future versions of the Scottish MFA will be to understand those material flows which are important to a circular economy in more detail.

Figure 4-1 and 4-2 below show the direct and raw material flows of materials through Scotland's economy in 2017, broken down by the four key material categories. The difference between these graphs is that Figure 4-1 shows the physical flows of traded materials. Figure 4-2 includes raw material requirements from imports and exports and these are included in the consumption figures as well.

Figure 4-1 Physical material flows through Scotland's economy in 2017

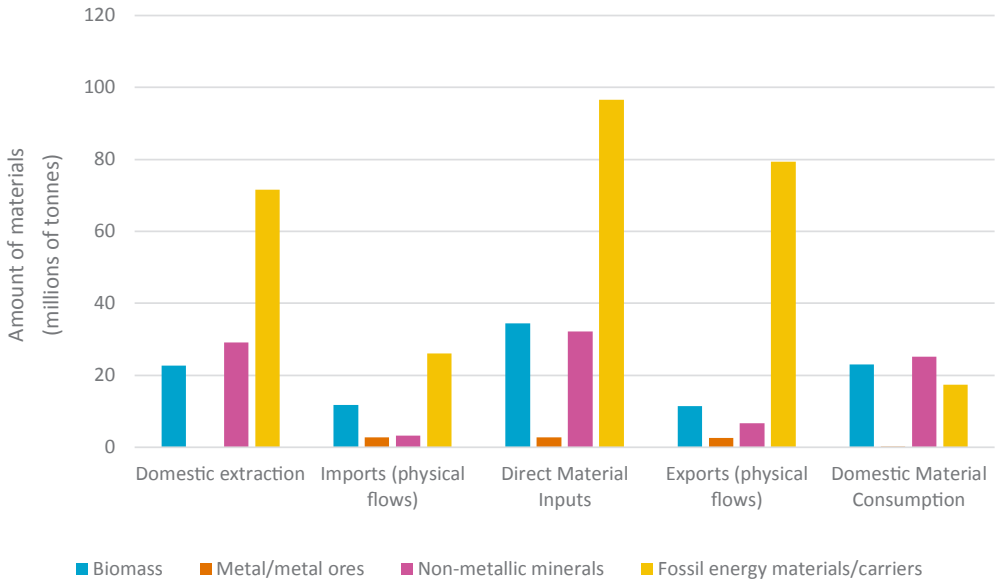


Figure 4-2 Raw material flows through Scotland's economy in 2017

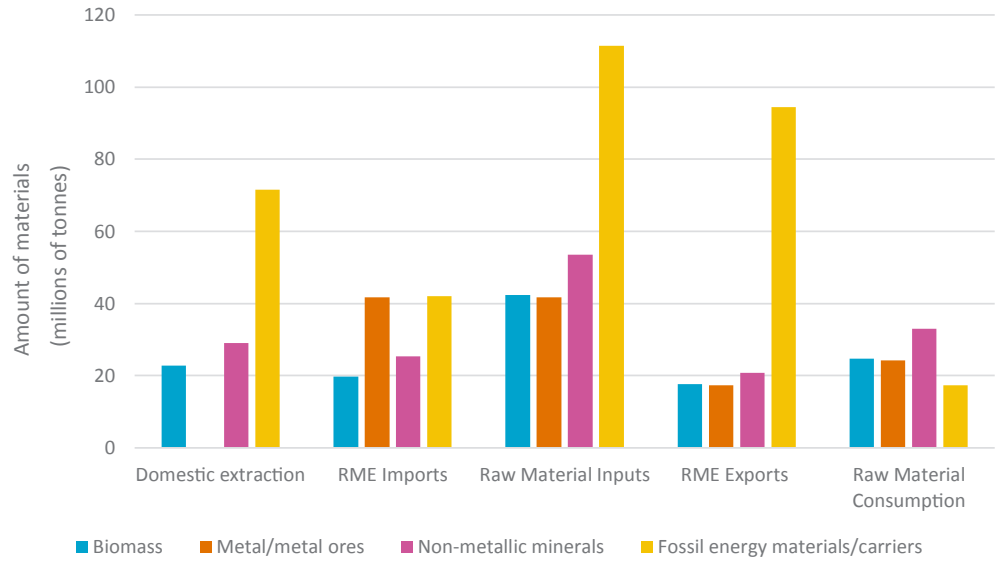
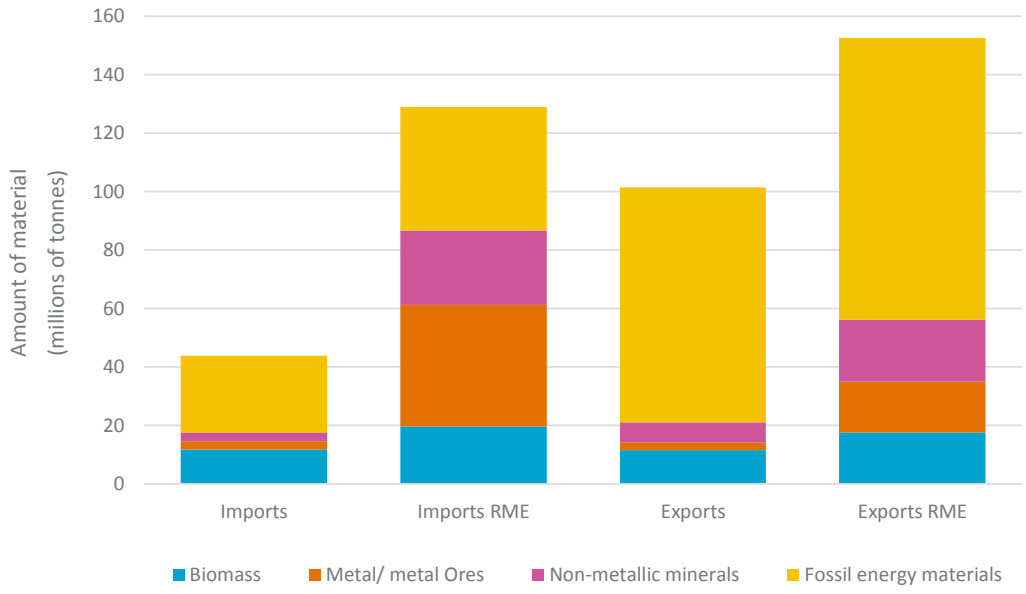


Figure 4-3 shows the difference between total physical and raw material flows for 2017. Imports increase by 193% and exports rise by 51% when raw material extracts are considered.

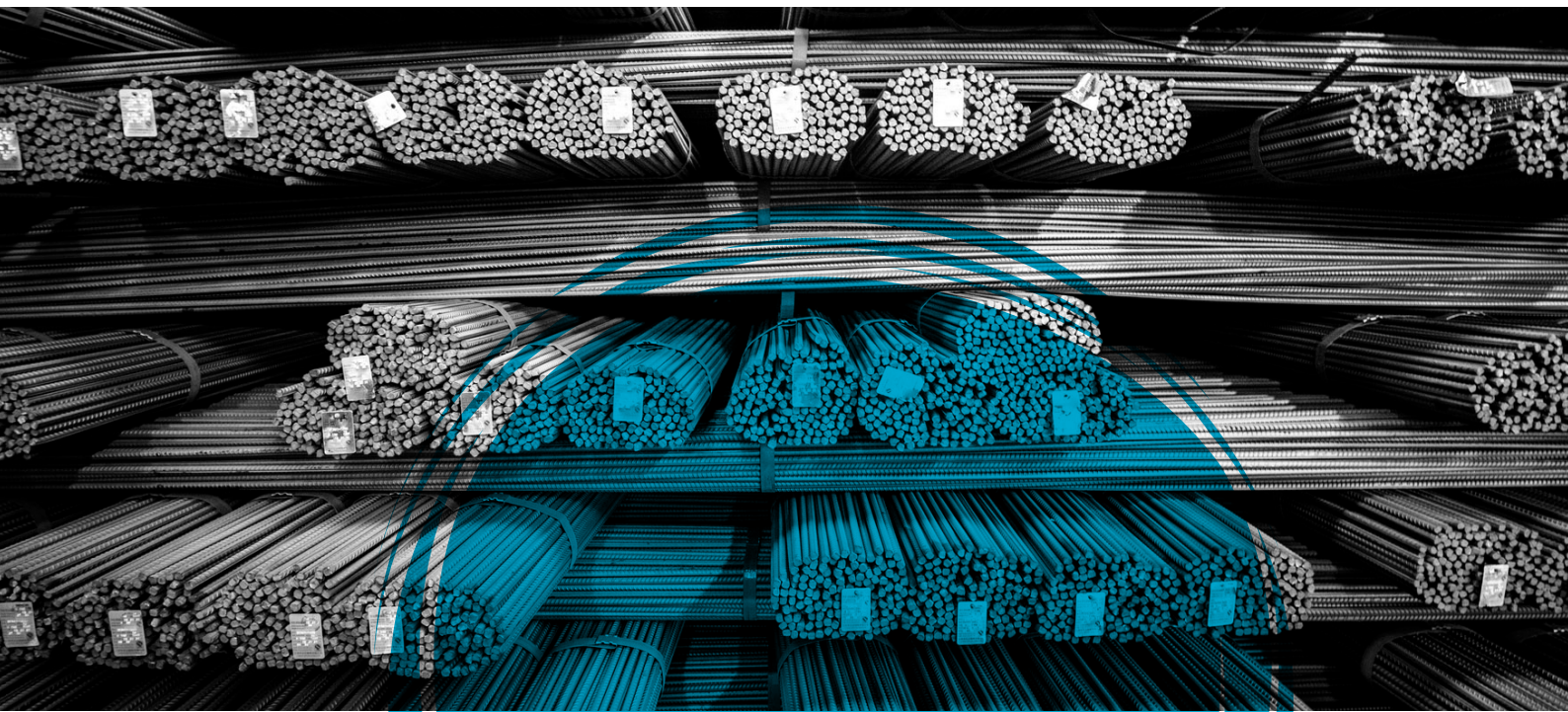
The net total of traded raw material equivalents (RME) is always larger than the physical trade, although this may not hold for particular material categories[31]. This is because it includes upstream raw material requirements for the production of traded semi-finished and finished products. In addition, while services are excluded from physical trade calculations, the RME includes the raw material used in generating those services. For example, import of electricity is not included in physical imports as it is not a physical flow, but the upstream raw materials that were required for producing the electricity (e.g. fossil fuels) in the exporting country is included in the RME imports.

For metallic and non-metallic minerals the difference between physical and RME trade is usually substantially larger because of these minerals in their primary form are often mixed with rocks, and the actual content of the mineral in rock is quite small (for example, based on the RME coefficient for iron ores in the EU-RME tool, production of a tonne of pure iron ore requires about 25 tonnes of iron-ore in its primary form).

Figure 4-3 Comparison between physical and raw material flows for traded materials in 2017



[31] Biomass based goods in particular

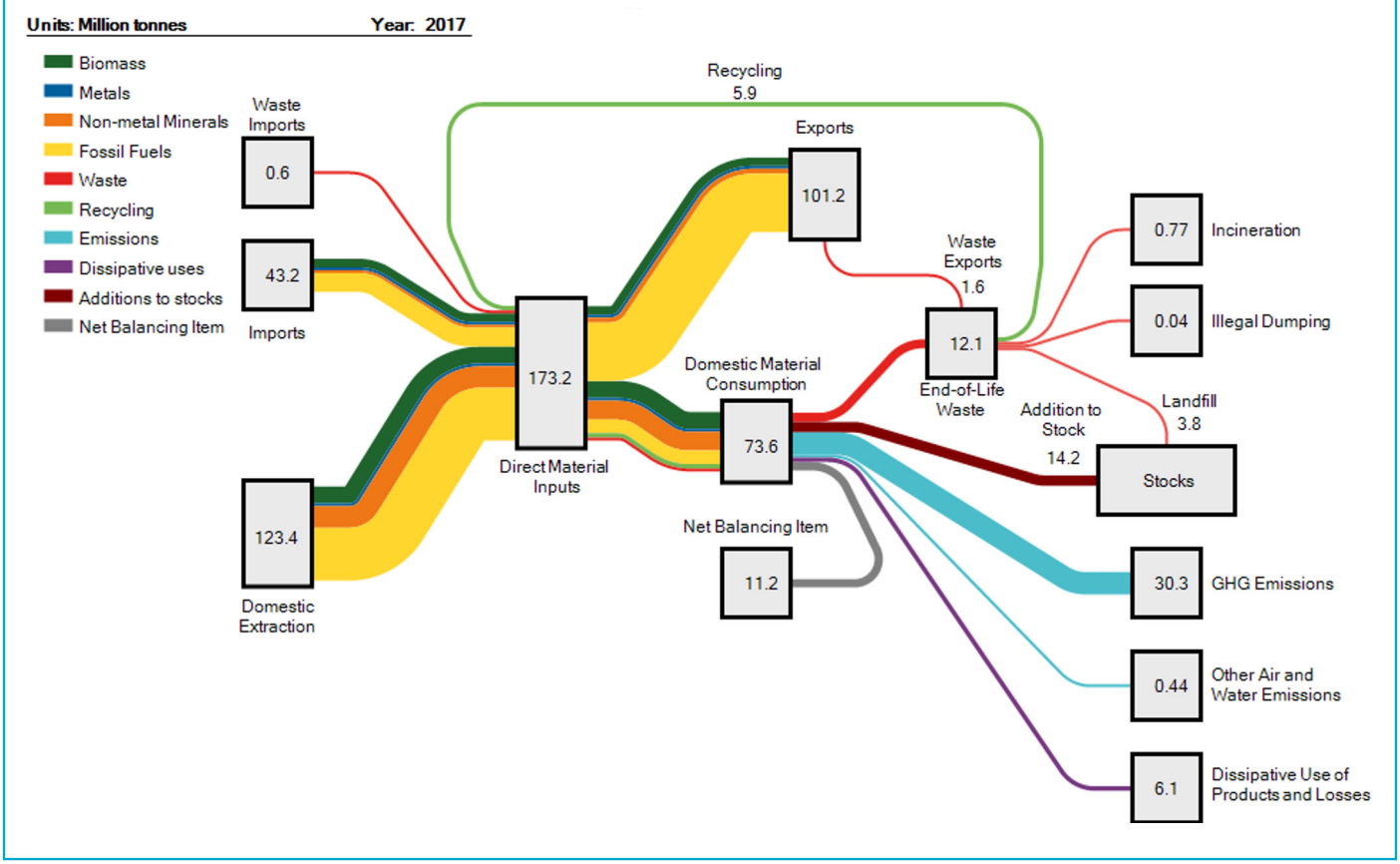


4.2 The Scottish MFA in 2017, Sankey diagrams

The material flow outputs of the Scottish MFA have been visualised in a Sankey diagram in Figure 4-4. This is a useful format for showing the quantities of materials and waste in a single year. The flows are displayed as million tonnes of material.

It should be noted that the estimates of some indicators (DMI, DMC) displayed in the Sankey diagrams are different from the actual estimates of these indicators in the Scottish MFA model. This is due to the separation of recycling and waste flows in the Sankey diagram. It should also be noted that the reported overall recycling flow (5.9 Mt in direct material terms) also includes soil recycling. If soil recycling is treated as backfilling, the recycling flow will be significantly smaller (approximately 2.5 Mt). Greenhouse gas estimates are weight based, rather than carbon equivalents and so not comparable with published carbon footprint accounts.

Figure 4-4 Physical Material Flows in Scotland in 2017, millions of tonnes



4.3 Trends in Scottish material flows for 2011-17

The following section reviews the trends in material flows for Scotland between 2011-17.

Figure 4-5 presents the trends in Domestic Extraction (DE), Direct Material Inputs (DMI) and Domestic Material Consumption (DMC). DE and DMC have decreased overall between 2011 and 2017, whereas DMI have increased slightly. The overall changes are small compared to the total tonnages of materials involved. DMC fell 10% between 2011 and 2017 but only 1% in the last 5 years for which data is available.

Figure 4-6 presents trends in Domestic Extraction, Raw Material Imports, Raw Material Exports and Raw Material Consumption for 2011-17. RMC has large year on year variation, although 2011 and 2017 tonnages are similar. RME Imports and RME exports are more variable than domestic extraction.

Figure 4-5 Trends in direct material flows for Scotland, 2011-2017

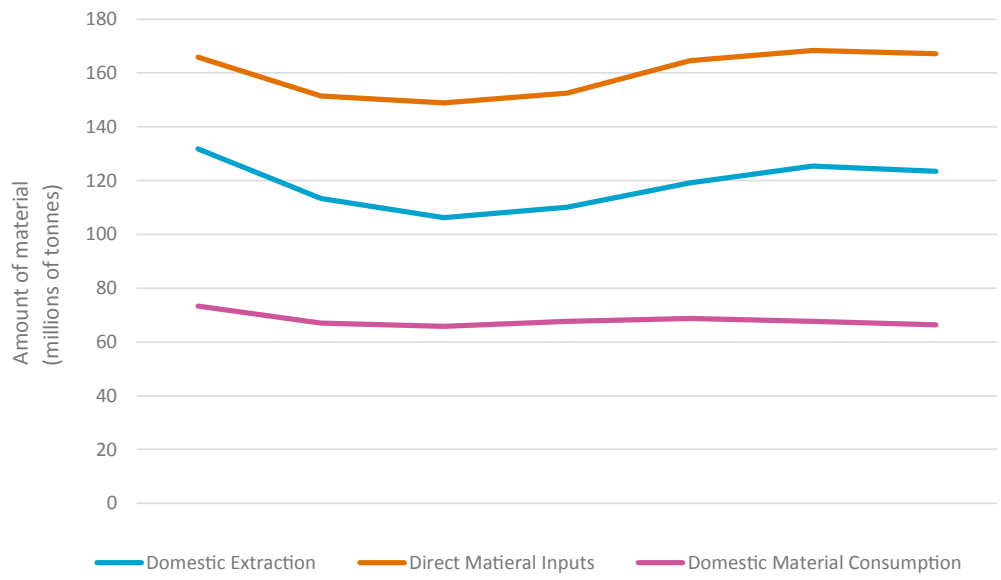
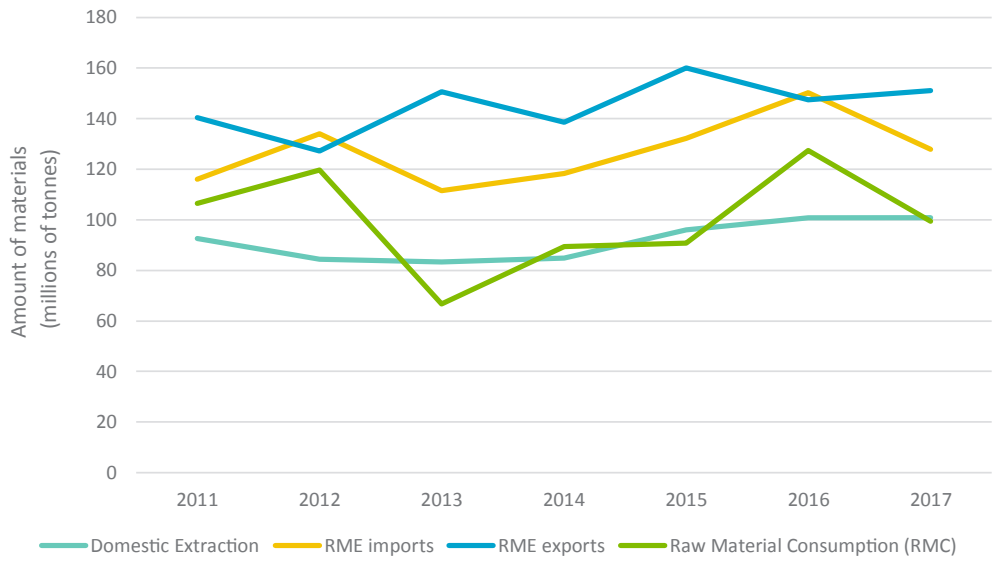


Figure 4-6 Trends in raw material flows for Scotland, 2011-2017

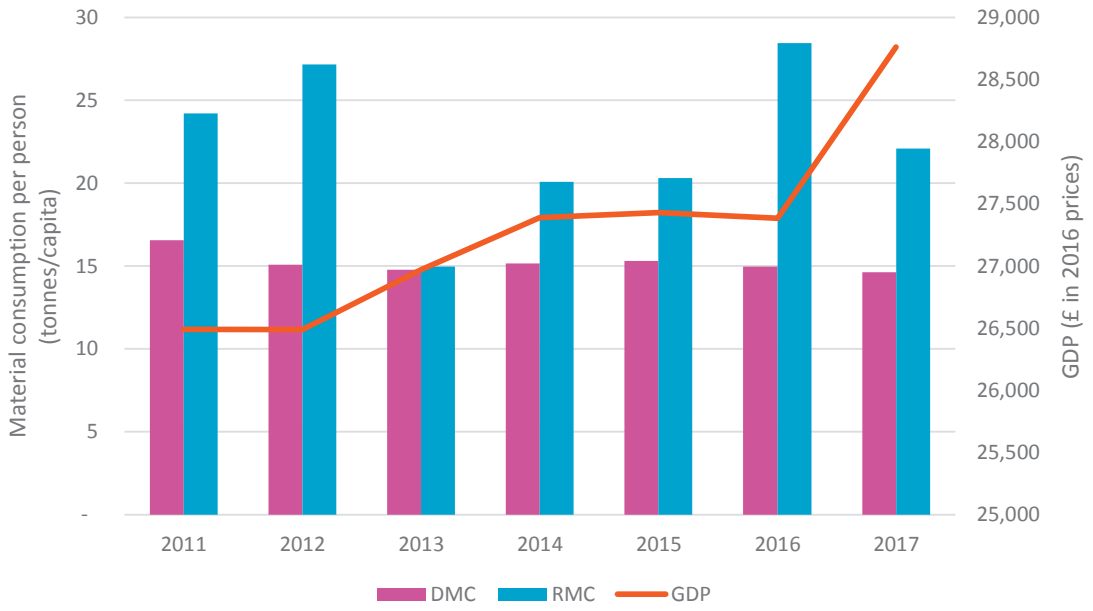


Zero Waste Scotland's Decoupling Advisory Group recommends that Scotland should aim to "Absolutely, rapidly, permanently and fairly reduce its consumption of natural resources"[32]. The Scottish MFA can be used to measure whether decoupling from GDP and population growth is occurring in a relative or absolute manner, how fast this is happening and whether the change is permanent.

Figure 4-7 presents an index of real Gross Domestic Product (GDP) and Domestic and Raw Material Consumption from 2011 to 2017. While real GDP increased slightly during this period, DMC and RMC have decreased. This suggests that decoupling of GDP from material requirement has occurred in Scotland over this period, and the Scottish economy is becoming less material intensive over time. Caution should be used in this interpretation, particularly with regards to RMC as the trend is so variable.

It is important to note that this result does not prove a causal link; there may be no or only limited relationship between these variables. Greater understanding of the relationship between these variables is required in further studies.

Figure 4-7 Index of Real GDP (2016 prices)[33], Domestic and Raw Material Consumption, for Scotland in 2011-2017



[32] Zero Waste Scotland (2020) Decoupling Advisory Group Report. [33] Scottish Government (2019) GDP Quarterly National Accounts 2016 prices from 2019 Q4 dataset.

Figure 4-8 Trends in material sub-categories for Scottish Domestic Material Consumption 2011-17

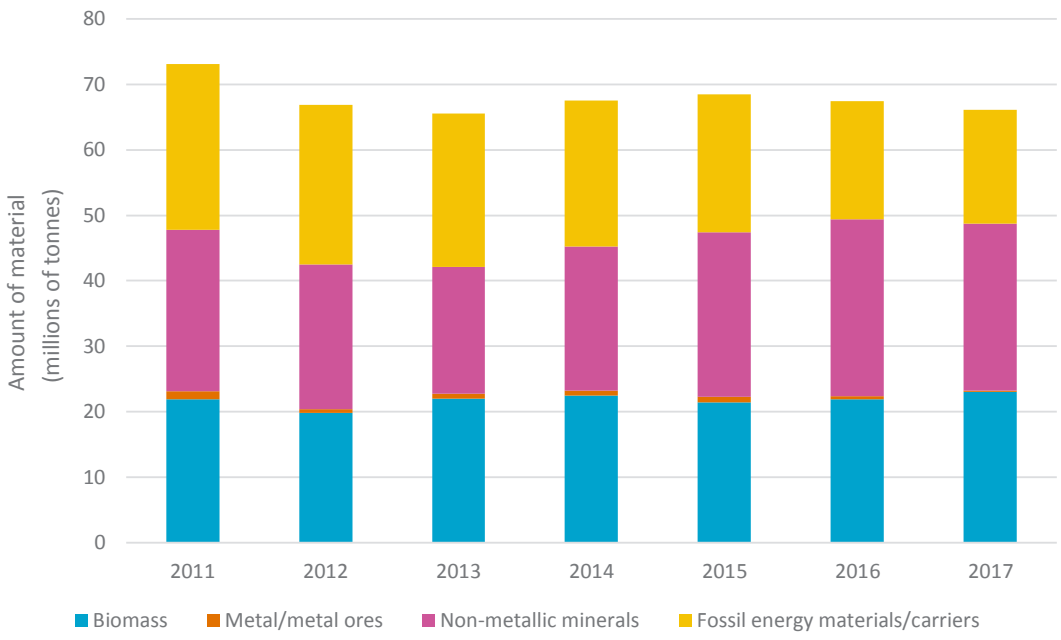


Figure 4-8 shows the trends in material sub-categories for 2011-17 for Scottish Domestic Material Consumption. Fossil energy material carriers and metal ore consumption have fallen, biomass and non-metallic mineral consumption has increased.

The Scottish MFA results indicate that Scotland added on average 15.5Mt of materials in stock each year between 2011-17.

4.4 Comparisons with EU MFAs

The results of the Scottish MFA were compared to the Material Flow Accounts for the EU 28 published on Eurostat[34]. The methodologies of the Scottish MFA and EU MFAs (including the UK MFA) differ regarding trade data. The Scottish model includes an additional layer of modelling to ensure intra-UK trade is considered, a step that UK and EU MFAs do not require. This creates an element of uncertainty in comparisons to these MFAs which must be considered with any interpretation of the results.

4.4.1 Domestic extraction comparisons

Figure 4-9 presents per capita Domestic Extraction (DE) for Scotland and the EU-28 in 2017. At 22.8 tonnes per capita, Scotland's DE was the fourth highest in Europe. Average DE for the EU-28 was 11.3 tonnes per capita, whilst the UK has the fifth lowest DE in Europe (6.7 tonnes per capita). Note that the UK figure includes an estimate of Scotland's material extraction. Scotland's small population compared to the rest of the UK means the effects on the overall UK per capita figure is small.

[34] Eurostat (2020) Material Flow Accounts.

Figure 4-9 Per capita Domestic Extraction for Scotland and EU-28 countries, 2017

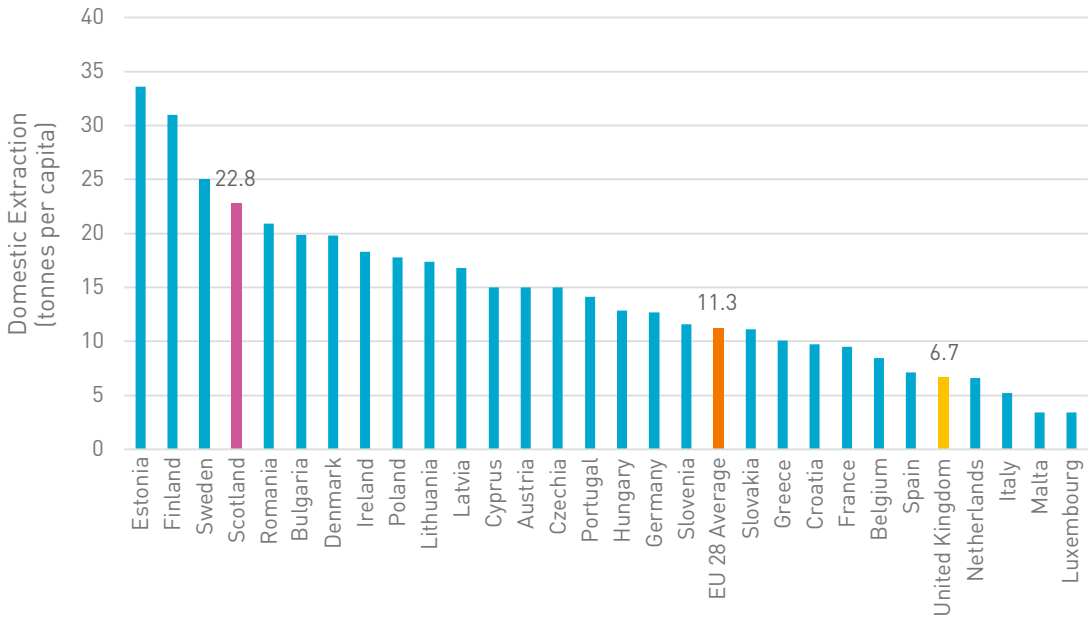
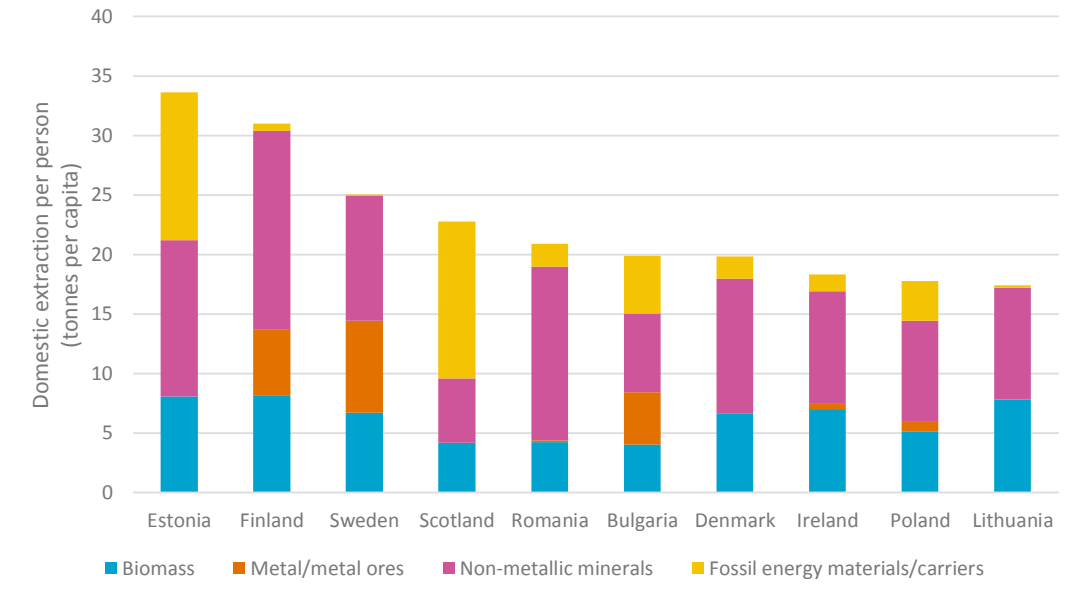


Figure 4-10 shows the domestic extraction broken down by material type for the nine largest extractors in the EU-28 and Scotland. Scotland's fossil fuel extraction is the main reason for its relatively high extraction rates, accounting for 58% of the total.

Figure 4-10 Domestic Extraction per capita, showing material type, for the nine highest extractors in the EU and Scotland, 2017



4.4.2 Domestic material consumption comparisons

Figure 4-11 presents the Domestic Material Consumption per capita in 2017 for Scotland and the EU-28. At 12.9 tonnes per capita, Scotland's DMC is slightly below the EU average (13.3) but higher than the UK's (8.6).

Scotland's DMC is much lower than its DE. This is because, whilst large amounts of materials are extracted in Scotland, large proportions are exported (in fact, Scotland is a net exporter of materials).

Note that the EU does not require countries to submit data on RMC so it was not possible to compare the Scottish MFA RMC figure to the EU-28 countries individually.

Figure 4-12 shows a comparison between the Domestic Extraction and Domestic Material Consumption per capita for the UK and Scotland. The high volume of fossil fuel extraction means Scotland's per capita domestic extraction is higher than the UK's. However, biomass and non-metallic extraction levels are also higher in Scotland.

Scotland's DMC is lower than its DE because much of the fossil fuels extracted domestically are exported. In contrast, the UK's DMC is higher than its DE, reflecting the fact that it is a net importer of materials. Scotland's DMC is 44% higher than the UK DMC.

Figure 4-11 Per capita Domestic Material Consumption for Scotland and EU-28 countries, 2017

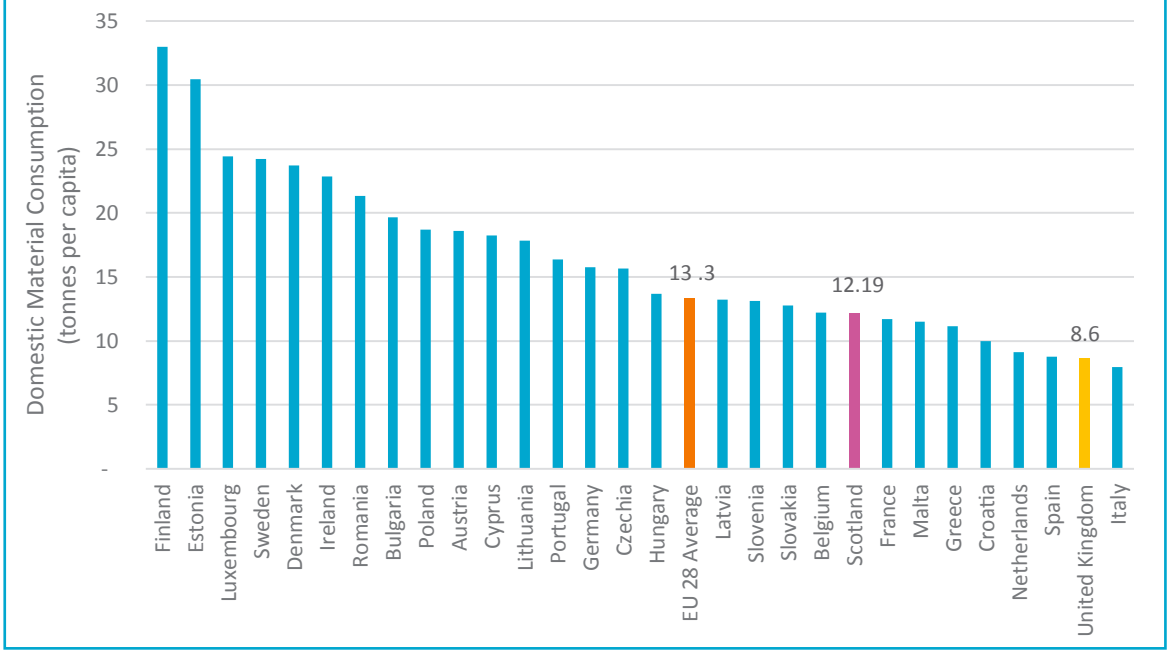
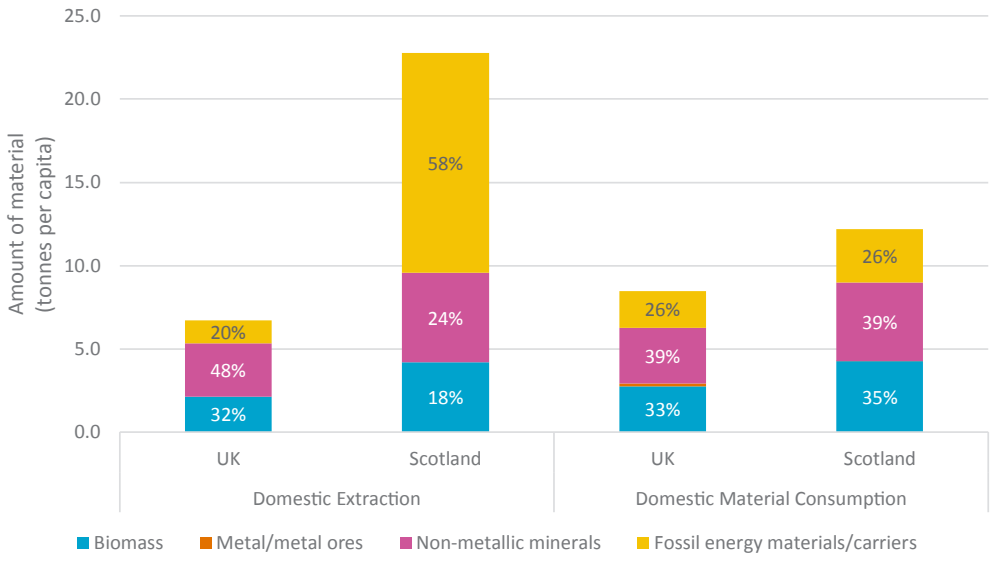


Figure 4-12 Per capita Domestic Extraction and Domestic Material Consumption comparison between the UK and Scotland, 2017



4.5 Comparison with UK MFA

Note that the UK does not publish RMC figures as part of the EU MFA dataset so a comparison of the UK and Scotland's RMC cannot be made.

An additional study was conducted to understand the difference between the Scottish and UK material consumption noted in Figure 4-12 above. A regression analysis was used to consider if economic, geographic and population based factors contribute to higher DMC levels. The following variables were found to be most significant:

- Population size
- Degree heating days (a measure of the number of days average temperature falls below 18°C).
- GPD per capita
- Population density

Of these, the most statistically significant were population size and degree heating days. Population size had a negative correlation with DMC per capita. Larger populations are expected to make more efficient use of shared amenities, including roads, bridges and buildings. Because such amenities require large amounts of materials, more efficient use of them may noticeably reduce material consumption per capita. So, Scotland's higher DMC per capita compared to the UK may be partly due to its smaller, more rural population requiring more materials for shared amenities.

Heating degree days were found to have a positive correlation with DMC per capita. The higher the number of heating degree days, the higher the DMC per capita. The likely explanation for this is that colder countries, with higher heating degree days, require more fuel to heat their homes. As heating fuels are usually either biomass or fossil fuel based, this would explain Scotland's higher than average consumption of these materials.

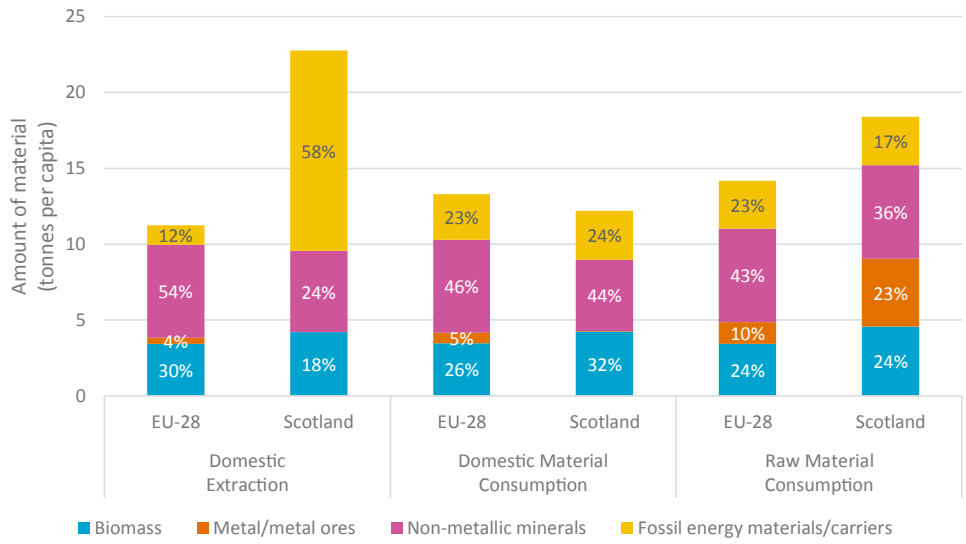
4.5.1 Material footprint (RMC per capita) comparisons

Whilst the EU does not require individual countries to report raw material flows, the total EU raw material flows are published[35]. This allows a comparison of Scotland's raw material indicators to the EU-28 average. This is shown in Figure 4-13.

Whilst Scotland's DMC is below the EU average (as noted in Figure 4-11), when the more complete measure of our resource consumption is considered, Scotland's RMC becomes higher than the EU average. Figure 4-13 suggests this is largely due to a higher than average consumption of metal and metal ores. Further investigation is required to understand this finding in more detail. The material footprint of Scotland can be compared to the worldwide average to give an indication of our relative impacts on a global scale. The world used 100 billion tonnes of resources in 2017[36]. The population was 7.5

[35] See Material flow accounts in raw material equivalents – modelling estimates (env_ac_rme) on Eurostat. [36] Circle Economy (2020) The Circularity Gap Report.

Figure 4-13 Domestic extraction, Domestic Material Consumption and Raw Material Consumption for Scotland and the EU-28 average, 2017



billion[37], meaning the global material footprint was 13 t per capita. Scotland material footprint including raw material use was 18 t per capita in 2017, or 38% higher than the global average. Some experts have suggested that global material consumption must be at or below 8 tonnes per person to be sustainable at present population levels.

4.6 Summary of findings

Key findings from the above analysis are listed below:

Scottish material flows in 2017

- Scotland's Domestic Material Consumption (DMC) was 66 Mt of materials, or 12.2 tonnes per capita;
- Scotland's Raw Material Consumption (RMC) was 100 Mt of materials, or 18.4 tonnes per person. This is 38% higher than the global average, which is 13.3 tonnes per person;
- 123 Mt of materials were extracted from Scotland's natural environment, of which 58% fossil fuels, 24% were non-metallic minerals and 18% was biomass. No metals were extracted domestically;
- Scotland is a net exporter of materials. 79% of physical material exports are fossil fuels;
- If the raw material requirements of imports are included, the mass of imports (129 Mt) exceeds that of domestic extracted materials (123 Mt);
- 12 Mt of material became waste in Scotland in 2017, of which 49% (6 Mt) was recycled.

Trends in material flows 2011-17

- Scotland's Domestic Material Consumption decreased by 10% from 2011-17. The Raw Material Consumption decreased by 7% over the same period but the year on year trend was much more variable.
- Real GDP increased 11% over this period, implying the resource intensity of Scotland's economy is declining, a process known as 'decoupling'.

Comparisons to other nations

- Scotland displayed higher levels of Domestic Extraction than the EU-28 average and the UK as a whole.
- Scottish Domestic Material Consumption is similar to the EU average but rises above average when raw material requirements are included;
- Scotland's Domestic Material Consumption per capita is 44% larger than the UK as a whole. A regression analysis showed that the difference is linked to population and climate. Scotland's lower population density means more materials are required per person for civic amenities including roads, bridges and public buildings. The colder climate means there is more demand for heating fuels.

The above findings should be interpreted with caution due to various data and methodological limitations.

[37] UN (2019) World Population Prospects.

5 Limitations, data gaps and improvements

This section describes the limitations, data gaps and suggested improvements for the Scottish MFA.

5.1 Limitations and data gaps

The results of the Scottish MFA should be interpreted with caution due to various data and methodological limitations. The main limitations of the Scottish MFA model are:

Data limitations

- The model relies on non-Scotland specific data sources to estimate certain flows (e.g. Scottish imports and exports in mass of materials are estimated based on imports and export volume data for the UK from ComExt database reported by Eurostat and scaled to Scotland using the Scottish and UK Input-Output financial tables). These estimations creates uncertainty in MFA outputs, particularly around trade data which must be considered when interpreting the results.
- There are gaps in some data trends for some inputs, requiring that averages are used to extrapolate the data across these gaps, therefore reducing the precision of outputs for these material flows. For example, since 2015 the data on various types of rock (limestone, sandstone, dolomite, etc.) are only available at an aggregate level of crushed rock. So, these data gaps were filled by extrapolating the ratios from the previous years.
- The limitation of using the EU-RME tool to estimate RME imports and exports for Scotland is that it uses the same coefficients for all countries in the EU. The tool adjusts the coefficients for different countries to account for differences in energy mix, primary and secondary metal ratios, etc. between the EU and the specific country of focus. However, to incorporate these adjustments in the Scottish MFA model would require Scotland specific annual data for these flows, some of which are not easily available. Moreover, incorporating these adjustments into the Scottish MFA model would also make the annual updating of the model by a non-expert extremely complicated.
- Lack of reliable hidden flow coefficients that can be used for estimating hidden flows associated with domestic extraction in Scotland. This creates a gap data in the Scottish Material Flow Accounts, which may be a sizeable one given the unaccounted-for materials include quarry overburden.
- Export of crops seems to be higher than domestic extraction, which is unlikely. Similarly, Scottish export of live animals and animal products seems to be larger than production of these products. While some of it can be explained by the high level of intra-UK trade, it is likely that this anomaly arises a result of using scaled UK level trade to estimate Scottish trade flows.
- Some of the flows under Domestically Processed Outputs (DPO) and balancing items could not be estimated due to lack of data (Scotland specific or otherwise).
- Post-2017, the publication of some datasets, particularly those based on UK reporting to Eurostat, will be affected by changes due to Brexit. The new reporting structure for these datasets is unknown at the time of publication but will be incorporated into the Scottish MFA model in future years.

Model limitations

- The model runs 3-4 years behind current times due to the publication dates of some of the supporting datasets (in particular the Scottish and UK IO tables). This means the Scottish MFA will not reflect the latest trends in material consumption. Whilst this is within the normal range of time-lags for MFA publications, it should be taken into consideration whenever the results of the Scottish MFA are used to support decision making.
- There is a trade-off between precision of outputs and developing a model that can be annually updated with ease by non-experts. For example, the detailed data on biomass extraction in 2016 compiled by Zero Waste Scotland has not been used in the model as some of the data for earlier years could not be located using those sources. So, we have reverted to more aggregated level of biomass extraction data for Scotland from Scottish Government which are readily available and updated annually.

- Challenges associated with developing mappings between different product categories/sectors, and the accuracy of mapping one set of codes onto another.

Scottish specific data limitations
The following list includes datasets which are not reported as required for the purposes of the Scottish MFA. Some datasets are not reported in tonnages, or annually at the Scottish level. Annex 1 of this report can be referred to for a full explanation of how each gap was managed.

- Domestic extraction of biomass:
    a. Production of fodder crops expressed in tonnes;
    b. Extraction of wood fuel and other extraction from forests (excluding production of timber);
    c. Aquatic animals other than wild fish catch and aquatic plants (e.g. seaweeds); and
    d. Hunting and gathering.

- Domestic extraction of non-metallic minerals:
    a. Various non-metallic minerals (Barites, Fireclay, Silica sand, etc.).

- Imports/Exports:
    a. Scottish specific trade data expressed in mass/volume broken down by rest of the UK and rest of the World flow;
    b. Fuel bunkered adjustments for residence principle.

- Domestically Processed Outputs Waste disposal to the environment (uncontrolled landfilling and fly-tipping):
    a. Dumping of materials at sea;
    b. Sewage sludge spread on soil;
    c. Pesticides;
    d. Seeds spread on the ground.

- Balancing items:
    a. Combustion related energy use from different activities (energy generation, transport, etc.);
    b. Nitrogen used for production of ammonia.

The results should be interpreted within the bounds of these limitations, particularly regarding conclusions about traded materials due to the reliance on UK-level data in volume units. However, most of the data used is from reliable, Scottish specific sources. The independent review by an international expert in Material Flow Accounts ensures that the best possible sources and method have been applied to the Scottish MFA.

5.2 Improving the Scottish MFA

The Scottish MFA is a tool designed to be used and updated for many years to come. The model could be improved and built on in the future, to increase its accuracy and expand our knowledge of material consumption further. The following improvements to the Scottish MFA should be prioritised in its future developments:

Scotland Specific Data on Physical Trade
This is the most crucial data gap for compiling a more accurate material flows account for Scotland. For this, data on trade in physical quantities or mass needs to be collected for Scotland. Data collection would be resource intensive and might require setting up new data collection infrastructure for Scotland. However, ONS and Her Majesty's Treasury (HMT) compiles this data for the UK as a whole, it may be possible to obtain disaggregated data for the devolved administrations. ONS and HMT may also be able to help develop the data collection infrastructure for Scotland if required.

Some Scottish specific trade data, especially biomass, could be obtained relatively quickly and easily. This could be a short-term solution to correct some of the anomalies related to biomass exports identified above.

Estimation of Hidden Flows
Estimates for hidden flows in the Scottish MFA model could not be included in the model due to limited availability of data. The hidden flows can be significant for some of the material flows (such as quarrying and agriculture). These are estimated based on coefficients, where the coefficients available for the UK are quite dated (from around 2005). The University of Leeds have been assessing different methods for conducting MFAs, taking into account indirect and hidden flows for the UK. Once the results of this study are published, they can be used to construct hidden flows for Scotland.

Scotland specific data improvements

The Scottish specific data gaps outlined in Section 5.1 should be addressed as a priority. This could be done by working with data collectors to ensure the relevant data is gathered and agree consistent methodology to fill historic gaps for annual model updates.

Future Extensions to the Scottish MFA Model

Useful extensions to the Scottish MFA model are:

- Full carbon accounting for different material flows such as domestic extraction, imports, exports and waste management;
- Detailed flows of specific materials, such as plastics through the economy. Management of plastic flows could benefit a more targeted material insight. The current approach to incorporating plastics into material flow accounts is not conducive to an accurate representation of plastics flows;
- Incorporating renewable energy generation and other relevant energy flows; and
- Introduction of a transport services flow associated with material extraction, imports, exports and waste disposal.

6 Conclusion

This study developed the first complete and detailed Material Flow Accounts for Scotland. It shows the inputs, stocks and outputs of materials flowing through the Scottish economy for 2011-17. The Scottish MFA was developed on the same principles as the Eurostat MFA models for EU nation states. This utilised one of the most well-recognised MFA approaches developed. Scottish data was for most of the datasets and an external peer review established the quality of the study.

The Scottish MFA has many outputs. Some of the most significant findings included:

- Scotland's Domestic Material Consumption was 66 million tonnes of materials, or 12.2 tonnes per capita in 2017;
- Scotland's Raw Material Consumption (RMC) was 100 Mt of materials, or 18.4 tonnes per person;
- Scotland is a net exporter of materials and our greatest exports by mass are fossil fuels; and
- Scotland's material footprint has decreased by 7% between 2011 and 2017. As GDP has risen over this period, this implies decoupling may be occurring.

The study did have limitations, including data gaps and inaccuracies in modelling which will be improved on over time to allow the Scottish MFA to guide more sustainable material consumption effectively.

As part of the Scottish Government's commitment to transition Scotland towards a more circular, sustainable economy, it is essential to improve understanding of material flows, and reduce overall material consumption. The Scottish MFA is a vital step in this process because it tell us so much about our current material consumption. The task is now to reduce the amount of material entering our economy and improve circulation of the materials consumed before they become waste. The Scottish MFA will continue to track, influence and measure progress towards this goal.

Annex 1: Detailed Modelling Methodology

This section describes the data sources, assumptions and calculations used to construct different material flows and indicators in the Scottish MFA model. Links to data sources are provided on the Scottish MFA model published on the Zero Waste Scotland website.

Biomass Extraction

There are four main categories of biomass extraction in the Scottish MFA model. These are:

- Crops (excluding fodder crops);
- Crop residues (used), fodder crops and grazed biomass;
- Wood; and
- Wild fish catch, aquatic plants and animals, hunting and gathering.

Live animals are not included in biomass extraction. However, live animals and animal products (meat, dairy, eggs, etc.) are included in the import and export flows as products originating from biomass.

Tonnage data on domestic biomass extraction and livestock are generally well published and of good quality at the Scotland specific level. Data for crops harvesting, wild fish catch and timber production are updated and released annually from the Scottish Government.

Data on fodder crops (including grass) production are published in terms of hectares of land used in production. These are converted to tonnage of fodder crops production using dry weight yield factors for Scotland or UK (when Scotland specific yield factors were not available).

Crop residues for various types of crops were estimated using factors from EU-MFA. Grazed biomass was estimated using the livestock numbers and associated feed requirement factors based on energy requirements and herd multipliers following the methodology developed by the Land Economy Environment and Society Research Group, Scotland's Rural College (SRUC).

There was no data available for the following components of biomass extraction:

- Extraction of wood fuel and other extraction from forests;
- Aquatic animals other than wild fish catch and aquatic plants (e.g. seaweeds); and
- Hunting and gathering.

Minerals Extraction

There is no extraction of metal ores in Scotland. Data on minerals extraction in Scotland were sourced from the UK Minerals Yearbook (UKMY) produced by the British Geological Survey (BGS). The UKMY is published every two years (the latest publication, UKMY 2018, was published in March 2019 which contains the data up to 2017). Also, the UK Minerals Yearbook does not provide Scotland specific data for all minerals. However, the BGS does collect this data and have released it upon request.

Tonnage data were available from BGS for the following non-metallic minerals:

- Clay and shale
- Igneous rock
- Limestone and Dolomite
- Sandstone
- Sand and gravel (land-won)
- Barites
- Fireclay
- Peat
- Silica
- Talc

Since 2015, data on extraction of igneous rock, limestone and dolomite, and sandstone have been combined into one category, dolomite. So, from 2015, the extraction of these minerals was estimated based on average share of individual minerals in the total extraction of the three minerals.

The BGS also provides data on extraction of coal. However, the data on coal extraction is not available individually for different types of coals (e.g. bituminous, lignite, etc.). Where needed, it was assumed that 90% of the extracted coal in Scotland is bituminous (black coal), and the remaining is lignite (brown coal), as most of the coal found in Scotland is bituminous.

Fossil Fuel
For fossil fuel/energy carrier materials, the Scottish Government publishes oil and gas statistics for Scotland (where data is available for indigenous production), imports from and exports to the rest of the UK and the rest of the world.

Data for crude oil and natural gas liquids were available in tonnes, whereas data for natural gas were available in Gigawatt hours. This was converted to tonnes of natural gas using conversion factor provided in the energy conversion calculator from the Scottish Government website.

Fuel Bunkered Adjustments for Residence Principle
Fossil fuel imports and exports need to be adjusted for residence principle, which means that refuelling abroad by any Scottish unit (e.g. planes, ship, etc.) should be recorded as imports, while refuelling in Scotland by non-Scottish units should be recorded as exports. Scotland specific data on fuel bunkered by domestic units abroad and by non-domestic units in Scotland were not available. Therefore, UK data for fuel bunkered that was available from the UK-MFA has been scaled down to estimate fuel bunkered for Scotland. For scaling the UK data to estimate fuel bunkered for Scotland, a population-based scale was used, where population data for UK and Scotland were sourced from ONS.

It should be noted that the fuel bunkered data for the UK only accounts for fuel bunkered by UK units outside the UK and fuel bunkered by non-UK units in the UK, and refuelling by a unit from one of the UK countries in another UK country is not included. So, estimates for Scotland based on population will be an estimate for fuel bunkered by Scottish units outside the UK and fuel bunkered by non-UK units in Scotland. And therefore, it is likely to be an underestimation because it excludes fuel bunkered by Scottish units in the rest of the UK and fuel bunkered in Scotland by the units from the rest of the UK.

Imports and Exports
Tonnage based import and export data are not available for Scotland. So, UK trade data expressed in tonnes were scaled to produce tonnage-based import and export data for Scotland. The UK data were sourced from Eurostat's ComExt database, which provide tonnage-based export and import data for EEA countries by Combined Nomenclature (CN Code). The EU-MFA provides the mapping between CN codes and EU-MFA material categories.

For scaling the UK data, a sector-based Scotland-UK scale was developed using the Scottish and UK Input-Output (I-O) tables. The Scottish I-O tables provides data on imports from and exports to the rest of the UK and the rest of the world, while the UK I-O tables provide data on imports from and exports to the rest of the world. So, the ratio between Scottish imports from (and exports to) the rest of the world and UK imports from (and exports to) the rest of the world provides the scale for Scotland's imports from (and exports to) the rest of the world. Then multiplying this scale with the ratio between Scotland's imports from (and exports to) the rest of the UK and imports from (exports to) the rest of the world provided the scale for Scotland's imports from (and exports to) the rest of the UK[38].

Applying these scales to the UK trade data from the ComExt database generated the tonnage-based estimates for Scottish imports from and exports to the rest of the world and the rest of the UK by CN code. This was then converted to Scottish import and exports by Scottish MFA material categories based on the mapping from the EU-MFA[39].

Given that there is Scotland specific tonnage-based data for import and export of oil, gas and waste, these values were used for these material categories instead of the trade data estimated based on the UK data.

Finally, to estimate the RME imports and exports from the physical imports and exports for Scotland estimated above, the RME coefficients from the EU-MFA were used. For this the estimated Scottish trade data by CN Code were converted to trade data by EU's 182 RME product categories. However, the RME coefficients uses a hybrid approach (including tonnages, monetary values, and tonnes of oil equivalent for different RME codes). Therefore, the Scottish trade data by RME code were also generated accordingly with tonnages, monetary values, and oil equivalents.

[38] The scales can be found in the "Scale" tab within the supplementary calculation file. [39] The mapping can be found here.

Multiplying the estimated Scottish hybrid RME trade data by the EU-MFA RME coefficient matrix generated the RME imports and exports for Scotland.

Rock export and RME export
The data on crushed rock export in tabs COMEXT Export and RME Export in the main MFA model were modified to account for anomalies in crushed rock export. The super quarry in Glensanda exports large tonnages of crushed rock to the UK and overseas every year. This is not picked up in the standard Scottish MFA approach for estimating exports as these are based on UK level data.

The annual tonnages of export from Glensanda to the UK and overseas are recorded by the Department for Transport in the UK port freight annual statistics. Since Glensanda only exports crushed rock, it is always transported by sea and this makes up the vast majority of Scottish rock export (99.9% according to 2015 Scottish Aggregate Survey which gives a snapshot of trade for 2012), the data for rock export on Glensanda is a reasonable substitute for Scottish level modelling of rock export from Scotland. The data from DfT matches well with the data from the Scottish Aggregates Survey, which estimates rock export from Scotland in 2012 (5,578,000t exported, 1% difference to DoT data).

The following updates were made to the Scottish MFA model. Crushed rock falls under the Scottish MFA category: "MF31 Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)".

The export and RME export tonnages in the main modelled were altered to reflect the Glensanda port statistics data from the Department of Transport. It is assumed physical and RME exports are both equal to the Glensanda exports. The Glensanda exports are higher than the RME export figures and RME must be equal to or higher than physical flows. The supplementary models have not been changed. This approach underestimates RME rock export but is considerably more accurate than the original approach. A spot check of the 2016 model suggested that this approach underestimates RME exports by 7%. The resulting impact on RMC per capita is about 1%. Future versions of the Scottish MFA will include full changes to the supplementary models to account for this addition to the standard model more accurately.

Emissions to Air
Data on emissions to air, greenhouse gasses (GHGs) and other air pollutants were sourced from the National Atmospheric Emissions Inventory (NAEI). NAEI published data on non-GHG air emissions in thousand tonnes, while data on seven different GHGs are combined into one category and expressed in terms of tonnes of GWP (global working potential) CO_2 equivalent (CO_2e).

To estimate the emissions by individual GHGs in tonnes, data on the seven GHGs for Scotland were collected from an existing 2016 study by Aether and Ricardo AEA which provided the GHG breakdown for Scotland up to 2014[40].

Emissions to Water
The data on emissions to water was sourced from the EU E-PRTR database. Although the data source is not Scotland specific, the data for the UK provides a fine geographical resolution enabling selection of Scottish river basins. Total emissions to water include pollutant release (i.e. direct emissions to waterbodies) and pollutant transfer (i.e. emissions into wastewater) for various emissions to water.

Waste
Data on waste destinations were sourced from the Scottish Environment Protection Agency's (SEPA) data on Waste from all sources (WFAS). For the Scottish MFA, the data needed were only waste landfilled, incinerated, recycled and composted.

There were no data available for illegal disposal of waste (disposal to uncontrolled landfills as well as fly tipping). It was assumed that the waste disposed to uncontrolled landfill and fly tipping amounts to 1% of the waste disposed to controlled landfills. No data were available for waste dumped directly into sea.

Dissipative Use of Products and Dissipative Losses
Data on application of mineral fertilisers were

[40] Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 – 2014 (link).

sourced from Scottish Government agriculture data, where the data was expressed as weight of the nutrient (e.g. nitrogen, phosphorus, etc.). These were converted to fertiliser tonnages using conversion factors from the EU-MFA.

Application of organic fertilisers (manure) were estimated based on Scottish livestock numbers using conversion factors from the EU-MFA.
No robust data were available for the following dissipative uses of various products:

- Sewage sludge;
- Pesticides;
- Seeds; and
- Salt and other thawing materials spread on roads (including grit).

Balancing items

Balancing items were calculated based on the EU-MFA methodology which is described in detail in the EU-MFA Handbook 2018. Balancing items on the input side included:

- Oxygen for combustion processes
- Oxygen for respiration of humans and livestock; bacterial respiration from solid waste and wastewater
- Nitrogen for Haber-Bosch process
- Water requirements for the domestic production of exported beverages

Balancing items on the output side included:

- Water vapour from combustion
- Gases from respiration of humans and livestock (CO_2 and H_2O), and from bacterial respiration from solid waste and wastewater (H_2O)
- Excorporated water from biomass products (i.e. water content of biomass products)

Data from other Scottish MFA flows were used to calculate most of the items based on coefficients from the EU-MFA. Data on use of nitrogen in production of ammonia were sourced from USGS data on estimated nitrogen usage in the UK. In the absence of a reliable scaling factor, a basic assumption was made that 25% of the nitrogen used in the UK is used in Scotland.

Indicators

Various MFA indicators were calculated for Scotland using the different types of material flows estimated in the Scottish MFA model. For analysing decoupling of Scottish GDP from material requirements for Scotland, Scottish GDP data were collected from the Scottish Government.

Sankey Diagram

The Sankey diagram was produced with the licenced software package, e!Sankey®. The Sankey diagram, being produced using an external software, will therefore not be generated within the model. However, data needed to generate the Sankey diagram for different years have been pulled together in a separate tab. The external Sankey diagram file contains the live links from the MS-Excel model, so that it can be used to produce Sankey diagrams for future years.

Annual Model Updating

The Scottish MFA model is set up in a way to enable non expert staff to annually update the data for the model. A separate model user guide was produced describing individual steps for annually updating the model with new data.

Annex 2: Peer review statement and response

An independent peer review was conducted of the Scottish Material Flow Accounts. The review was conducted by Dr Robin Curry of Queen's University Belfast in October 2020. It covered:

- A spot check of sample data points and calculations throughout the Scottish MFA model.
- Consideration on whether the most appropriate and up-to-date datasets have been used in the Scottish MFA and supplementary models;
- Comments on whether the data has been combined in the correct way in the Scottish MFA and supplementary models;
- A review of the technical report (particularly the description of the methodology and the main findings);
- Any recommendations on how to fill the data gaps identified in the technical report; and
- Comments on how the main results are communicated.

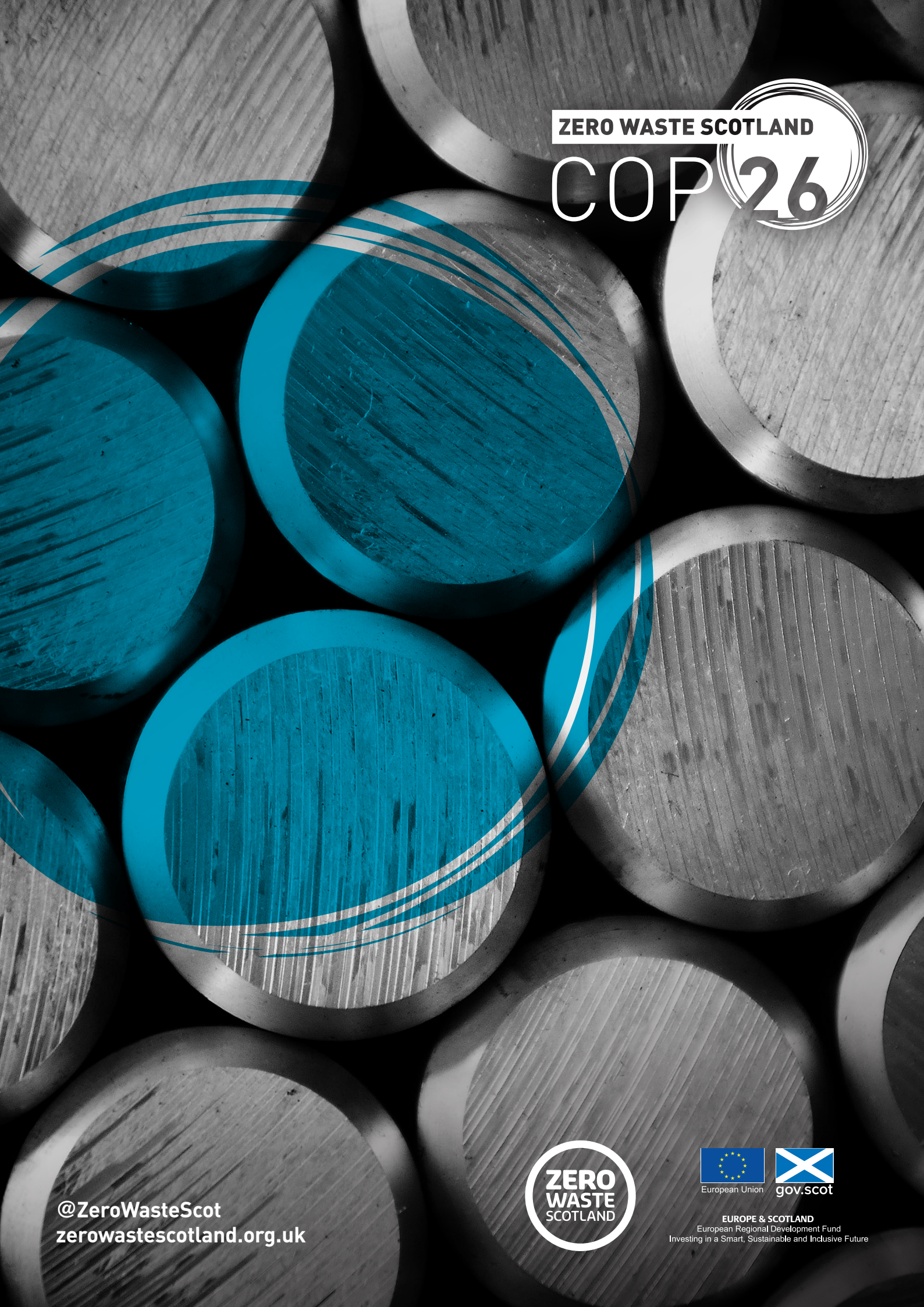
Additional research, to explore the difference in UK and Scottish material consumption, was conducted after the main results were analysed. The results of this analysis were added to the final report and are described in Annex 1, in the section headed "Rock export and RME export" and in section 4.5.1 in the main report. These updates were not covered by the external peer review but were thoroughly reviewed internally.

The following table summarises the main findings of the review and the responses taken.

Table A-1 Summary of peer review comments and responses

Peer Review comment	Response
Spot checks of model, general The spot checks highlighted a small number of possible anomalies in the sources of data used in the model. These were raised with Zero Waste Scotland as part of the peer review process and the subsequent explanation for the anomalies resulted in no changes being required to the Scottish MFA results (the anomalies raised by the PR and the Zero Waste Scotland response have been supplied as Supplementary Information).	Comments noted and no changes required.
Spot checks of model, specific recommendation (1) Assumption of percentage of waste to uncontrolled landfill and fly tipping at 1% requires further investigation.	This figure was based on expert advice from the Scottish Waste Data Strategy Board.
Spot checks of model, specific recommendation (2) A number of the reference links to data sources in the model are out-of-date and require updating. Also, the links to data sources in the model need to be improved to lead users to the actual document, rather than a generic web page.	All references, including hyperlinks, in the 2017 version of the model have been checked and updated if necessary. A note will be made in the user guide that this should be done in future versions of the model too.
Spot check between Scottish MFA sheets and indicator sheets General checks between the data references in the cells in Indicators with those in the Scottish MFA data sheets has not shown any errors.	Comments noted and no changes required.

Comment on the appropriateness and age of the datasets used in the model The most up-to-date and appropriate datasets have been used in the model (see comment above on dataset dates in the Scottish MFA).	Comments noted and no changes required.
Comment on how data has been combined in the Scottish MFA and supplementary models The combination of data in the Scottish MFA model and supplementary models is transparent and sound.	Comments noted and no changes required.
Technical report review, methodology and main findings The methodology is clearly set out and strikes a good balance between describing the background and development of the Scottish MFA model and presenting the outputs. Annex 1 provides a detailed modelling methodology, setting out data sources, assumptions, and calculations. The analysis of best available material data and the presentation of the main data sources used in the Scottish MFA is clear and transparent.	Comments noted and no changes required.
Technical report review, data gap improvements A particular strength of the report is the detailed description of the main data and model limitations, and areas for improvement. The recommendations on improving the Scottish MFA model make clear that this will be an iterative process and the recommendations for reducing data gaps and potential future extensions are clear and common-sense. Given the range of possible improvements identified, it might be useful to specifically identify priorities in terms of benefits to the Scottish MFA modelling and ease of completion, and I would highlight the following: Improvements to data: generation of Scottish-specific data on physical trade. Extensions to the Scottish MFA: full carbon accounting for material flows such as domestic extraction, imports, exports, and waste management.	Comments noted and no changes required. The authors agree with the suggestions for prioritising improvements.
Communication of results The report strikes a good balance between communicating the content of the technical report, and economy.	Comments noted and no changes required.
Summary comment In conclusion, I can confirm that my review had identified a requirement for important updates to the data sources but that there are no changes required to the Scottish MFA model.	Comments noted.



@ZeroWasteScot
zerowastescotland.org.uk

ZERO WASTE SCOTLAND

European Union
gov.scot

EUROPE & SCOTLAND
European Regional Development Fund
Investing in a Smart, Sustainable and Inclusive Future