# Vital South Australian material flows V1.0

## EVIDENCE REPORT

FINAL REPORT
12 May 2022

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We acknowledge and respect their deep spiritual connections, and the relationship that Aboriginal and Torres Strait Islander people have to Country.

We extend our respect to all Aboriginal and Torres Strait Islander peoples and their nations in South Australia, and across Australia.

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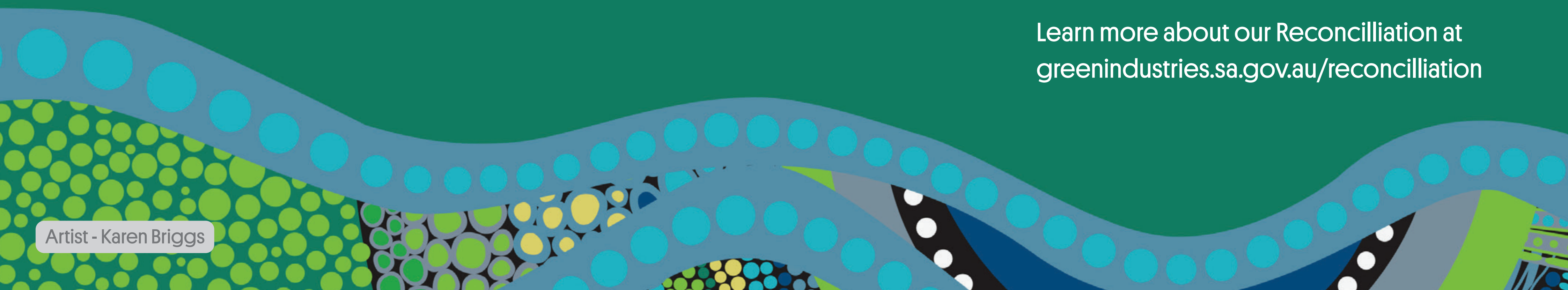

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## Important disclaimer

# Glossary

| Abbreviation | Definition |
|---|---|
| ABARES | Australian Bureau of Agricultural and Resource Economics and Sciences |
| ABS | Australian Bureau of Statistics |
| ACTA | Australasian Circular Textile Association |
| APCO | Australian Packaging Covenant Organisation |
| AusLCI | Australian National Life Cycle Inventory Database |
| C&D | Construction and demolition |
| C&I | Commercial and industrial |
| $CO_2e$ | Carbon dioxide equivalent units |
| E-waste | End-of-life electrical and electronic equipment |
| MCI | Material Circularity Indicator |
| MDF | Medium-density fibreboard |
| MFA | Material flow analysis |
| NCM | National Circularity Metric |
| NTCRS | National Television and Computer Recycling Scheme |

| Abbreviation | Definition |
|---|---|
| PV | Photovoltaic |
| SA | South Australia |
| TV | Television |
| UNU | United Nations University |
| WITS | World Integrated Trade Solution |
| WWTP | Wastewater treatment plant |

# Introduction

Green Industries SA has measured recycling activity and waste disposal to assess their performance against South Australia's Waste Strategy each year since 2003–04. As a result they have a detailed understanding of how materials are flowing out of the state's economy and are able to actively manage practices to improve the recovery and recycling of different material streams.

For Green Industries SA to lead South Australia's transition towards a more circular economy, a detailed understanding of how materials enter and flow through the economy – and across the life cycle of products – is necessary.

The goal of a circular economy is to: (i) intentionally design out waste; (ii) keep products, components and materials in circulation; and (iii) regenerate the natural environment. Extending the life of products and materials in the economy can reduce the amount of new material inputs and waste outputs. Understanding how materials flow through the economy will give Green Industries SA the overview needed to prioritise initiatives to achieve circularity.

This report quantifies and illustrates the flows of vital materials through the South Australian economy for the first time. As well as examining the whole state economy, the following four sectors are studied in detail:

- food and organics
- built environment
- electronics
- textiles

This report provides background on material flow analysis and the overall methodology, then delves into the models and results for the whole of SA and each focus sector. The results are presented in Sankey diagrams, which visually depict the flows of materials as they pass through the South Australian economy.

## ABOUT MATERIAL FLOW ANALYSIS

Material flow analysis (MFA)[1] is a method to study the physical flow of natural resources and materials into, through, and out of a well-defined system – in this case, the South Australian economy. The results of an MFA can provide valuable information to feed into policy making. The results can also help evaluate progress towards the overarching goal of managing resources more sustainably.

Over the past three decades, several government and supra-national organisations have published material flow analyses/accounts of varying detail and frequency, including the United Nations Environment Programme (1990-2017), Eurostat (2008-present), Statistics Denmark (1993-2017), Japan's Ministry of Environment (2006) and the UK's Office for National Statistics (2000-present).

In addition to government-driven initiatives, there is a wealth of knowledge being produced in the scientific literature, including regional MFAs [1], or analyses focusing on specific economic sectors.

On the international level, the Global Material Flows Database is published by the International Resource Panel of the United Nations Environment Programme [2]. It covers up to 13 categories of materials, and provides data for 150 countries. Other global online databases cover specific flows, with two prominent examples being energy [3], and water/land accounts [4]

[1] Can also be referred to as 'material flow accounting' when used at national or regional scale.

# Methodology

This baseline analysis – V1.0 – brings together data from multiple sources to provide a quantitative assessment of the materials that are moving through the South Australian economy, which has been illustrated using Sankey diagrams for the entire economy as well as for each priority sector.

The key to reading and interpreting Sankey diagrams is related to the width of each band which is proportional to the quantity being represented. Closed loops on the diagram indicate materials that are reused in the economy or used to produce secondary raw materials or for other purposes, preventing further extraction of natural resources. While Sankey diagrams are useful for visualising key material flows, they cannot represent all the detail contained in the underlying accounts.

Throughout the analysis, information was compiled on the consumption, use and end-of-life for different material streams within the South Australian economy. The analysis relied on publicly available data, a review of the scientific literature for each sector, as well as the use of relevant models developed by Lifecycles. Combined, this information paints a picture of the way materials flow through the South Australian economy – starting with the four main resource areas of biomass, metallic minerals, non-metallic minerals, and fossil-derived resources. This data was compiled in supplementary worksheets that are directly referenced by the Sankey diagrams.

As well as mapping the physical flows of materials and products, the embodied carbon of important flows was assessed to provide a greenhouse gas context to the material flows. This information helps to create a better understanding of which material streams are most impactful to the environment.

MFAs are typically stock and flow models that estimate the amount of material coming in, the stock in use within the economy, and the material coming out as waste. 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 (such as infrastructure or long-life goods) or becomes an output (such as exported commodities), or is waste or emissions to the air and water.

A simplification for this baseline study is that the economy is generally assumed to be in equilibrium. That is, the amount of material exiting the economy as waste in a given year is a fair representation of amount of new material entering. The exception to this is the electronics sector, where a complete stock and flow analysis was undertaken to reflect the dynamic nature of technologies and products that vary greatly over time.

## Data requirements and assumptions

While South Australia has strong datasets on waste that are generated through recycling activity surveys, linking these to the four priority sectors then combining with input data can be challenging. This first report should be seen as a 'line in the sand' with improvements in data to follow as more adequate systems are developed into the future.

This comprehensive MFA brings together many separately developed data sources on flows for material and products across multiple sectors. The type and level of data available, and the characteristics of each sector, mean that each required slightly different approaches. South Australian data sources have been used where possible with financial and/or national data used to fill gaps. Each subsection of this report provides a detailed overview of the data sources and the approach used for that sector.

Each model relies on assumptions to allow the characterisation of products entering the market, the duration of their stay in the economy, the amount of waste arising, its destination and management, as well as the characterisation of material categories. All assumptions – and gaps – are clearly identified to allow for improvement in future MFA studies.

## Carbon perspective

While the mass flow results provide valuable insights into the type and magnitude of the materials flowing through the economy there is no indication of the environmental impacts associated with these flows. A purely mass-based lens can result in a distorted view of the significant material streams in terms of their environmental impacts since they do not reflect environmental burdens. To counter this inherent bias, the mass flows associated with key material streams in each target sector were examined through a carbon lens, providing further context on the relative significance of different streams.

For each of the four sectors, life cycle inventory data was used to calculate the embodied carbon of key materials and products. The embodied carbon results are presented alongside the corresponding consumption. This comparison provides additional context by demonstrating that large material flows do not always result in equally large environmental burdens.  This is intended to show that the greatest benefits to the environment are not necessarily made by focusing on the largest material flows but instead by analysing which material flows have the largest impact. It should also be noted that environmental impacts have only been examined in terms of greenhouse gas emissions, which does not encompass all types of environmental burdens.

While embodied carbon gives an indication of the upstream impacts, it does not include the greenhouse gas emissions that occur during the use and end-of-life phases of the material. Where relevant, the greenhouse gas emissions over the life cycle of the product or material were discussed.

**Terminology: Embodied carbon**

'Embodied carbon' refers to the cumulative greenhouse gas emissions that occur during the production and distribution of a product or material.
This can also be thought of as the upstream greenhouse gas emissions that were required to create the desired product.

## Nutrient flows

Nutrients are a critical issue for the circular economy. As a precious resource for agricultural systems, their loss to air, landfills and receiving waters is a massive economic and environmental waste. They are also problematic as pollutants in water bodies due to eutrophication and contamination.

The Stockholm Resilience Institute highlights that the overuse and wastage of both nitrogen and phosphorous have passed planetary boundary conditions [5]. Declining stocks of these nutrients, particularly phosphorous, increases the price of fertilisers, and subsequently the cost of agricultural production. Wasted nutrients end up in aquatic systems potentially changing species compositions, causing algal blooms and other ecological damage.

Flows of nitrogen and phosphorous were evaluated and mapped for food and organics.

## Circularity indicators

Measuring progress towards a more circular economy is a challenge for any business, city, country or region. Different indicators and metrics are available for application over a range of scales. Some measure flows, some measure impacts, and some combine concepts to provide an overall circularity 'score'.

Much work is underway in Australia and across the world to develop and apply appropriate circular economy indicators at regional levels. To contribute to this, the two most commonly used metrics are applied to each target sector.

### 1. Material circularity indicator (MCI)

The MCI was developed by the Ellen MacArthur Foundation as part of a broader Circularity Indicators Project. The aim of the indicator is to examine the material flows of a product and to determine how restorative they are.

The single-score indicator gives a result of between 0 and 1 based on four components:

i. the proportion of feedstock from reused and recycled sources
ii. the destination of product at end of use (closed loop reuse and recycling are not a requirement)
iii. the recycling efficiency on both the input and output sides
iv. the product's intensity of use and lifespan compared to the industry average.

The calculation of the MCI can be represented in a simplified form as:

*MCI = circular flow index × utility factor*

The 'circular flow index' represents the proportion of material flows that are cycled (i.e. reused or recycled). Conversely, the 'linear flow index' measures the proportion of material flowing in a linear fashion (i.e. sources from virgin materials and ending up as unrecoverable waste). The circular flow index is found by subtracting the linear flow index from the total. The utility factor is found by multiplying the product's lifetime and intensity of use.

The MCI is designed for assessing circularity of individual products, but can be aggregated for a product portfolio. It is considered one of the more thorough circular economy metrics, as it considers circularity from a broader perspective than only waste management. The MCI is unique in that it considers the utility of a product (i.e. how intensely it is used and how long it lasts), which is an important aspect of a circular economy that is often overlooked in the development of metrics. When applying the MCI to an entire industry sector, as is being done in this study, the utility factor is no longer applicable (since it is calculated in comparison to the industry average).

### 2. National Circularity Metric (NCM)

The NCM was developed by Circle Economy, and most notably used in their annual Circularity Gap Report [6]. The metric aims to measure the degree of circularity within an economy. It is represented as a percentage and calculated as:

*NCM = total cycled materials ÷ total material consumption × 100*

The total cycled materials include waste recovered within the economy and the net trade balance of secondary materials.

The NCM is designed for large-scale regional analysis and thus is well suited to being used for calculation from regional material flow analysis data. While the MCI looks at both the input and output side of materials flows, the NCM skews the focus to the input side of the material flows. This does not mean the output side is ignored but instead that the circularity benefits of recycling the waste outputs are assigned to the destination of these output flows, where they are classified as inputs. Therefore, recycled materials that stay within the economy under analysis are counted within total cycled materials, but recoverable wastes that are exported from the economy are not counted.

# South Australia

This section presents the vital material flows through the South Australian economy. The purpose of calculating the flows as a whole is to provide a better representation of how the materials move through the state as a system. It also helps to contextualise the four focus sectors and how they fit within the overall picture which also highlights any significant gaps.

The South Australian material flows were modelled by combining the flows of the four focus sectors which were modelled in detail. Additional flows were then added by including the automotive, packaging, and energy sectors.

## Sector categorisation and key data sources

The product categorisations provided in Table 1 were developed to represent the largest material flows and to match them with the Recycling Activity Survey data categorisation [7], and to align the flows with the four main resource areas (biomass, metallic minerals, non-metallic minerals, fossil resources) whilst remaining consistent with the four-sector specific MFAs included in this analysis.

The data sources for the full South Australian model are from four other sector-specific MFAs, which will be detailed in the following chapters with organics and the built environment representing some of the largest material flows through the economy.

Other areas draw upon the following sources:

- Mining and energy statistics from the Australian Bureau of Statistics (ABS) and Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) as well as industry reports.
- Packaging information derived from the Australian Packaging Covenant Organisation (APCO) Australian Packaging Consumption and Recycling Data Report [8]; and paper production and consumption from mixed industry sources.
- Automotive sector data from ABS Sales of New Vehicles figures on imported vehicles, domestic truck trailer manufacture, and fuel consumption.
- A single energy sector is included for all non-transport fuel use. This is a simplification as fuels and electricity flow across all sectors of the economy but has been considered out of scope for this project.

Table 1 South Australia categorisation

| Product category | Data sources |
|---|---|
| Food | Food and organics analysis (page 13). |
| Paper and packaging | Paper: food and organics analysis (page 13).<br>Additional modelling for packaging flows. |
| Roads and bridges | Built environment analysis (page 36). |
| Construction | Built environment analysis (page 36). |
| Electrical and electronic | Electronics analysis (page 26). |
| Textiles | Textiles analysis (page 43). |
| Automotive | Additional modelling. |
| Energy | Additional modelling. |

## Modelling approach and assumptions

The MFA for South Australia was undertaken on a territorial basis and shows the main flows of material into, out of, and within the South Australian economy. Imports and exports to and from the South Australian economy include both interstate and international flows.

The MFA is a 'bottom up' approach in the sense that the data used is derived from individual sources within the main sectors of activity to build the picture of material flows across South Australia. This means there are some gaps around smaller material flows and sectors.

To capture these smaller flows, a 'top down' approach using economic accounts for total production and consumption for South Australia would be required, with material flows being assigned for each sector. A 'top down' approach was not used for the following reasons:

- the economic account data would not balance with key data sources from Green Industries SA's annual Recycling Activity Survey
- sector averaging in economic accounts introduces potentially significant errors in the large material flows – those which are most important to manage
- smaller flows are difficult to visualise in Sankey diagrams, especially when presented alongside much larger flows, so there is little value in refining them.

**Terminology: Consumption-based vs. Territory-based material flow accounting.**

Material flows of a region are generally calculated using a consumption or a territorial approach.

A consumption approach accounts for the material flows of all products consumed in the region. For example, for a car purchased in South Australia, the materials associated with the manufacture, distribution, use and end-of-life of the car would be accounted, regardless of the source of the materials. This methodology is based on the idea that material flows are driven by consumption, and that the impacts of production should be allocated to the consumer.

A territory-based approach considers where the material flows physically occur. Using the same example, the material flows associated with the manufacture of a car would be considered as belonging to the region of manufacture, while the material flows occurring during use would be counted in South Australia. One key argument for this approach is that management of material flows is best done in the region where they occur.

The same distinctions exist for other environmental flows such as cumulative greenhouse gas emissions and cumulative energy flows. Both views provide valuable information for policy making.

## Material Flow results

The MFA in Figure 1 shows that the three largest flows in South Australia are:

i. biomass into agriculture for both domestic consumption and export of food
ii. non-metallic minerals into the built environment
iii. exports of metallic mineral – principally iron ore and smaller amounts of copper and uranium.

The built environment drives the largest domestic flows and also represents the largest circular flow due to material recycling of concrete and rubble. The circularity of this sector is much higher than the diagram suggests, with a large quantity of materials being added to the stock each year. Even though the percentage of expansion of industry and population in SA is relatively modest at 0.78%, this expansion translates to a large flow compared to the relatively slow turnover and renewal of the built environment.

The cycling of nutrients – predominantly from agriculture and food waste – into South Australian soils is the other significant circular flow in this picture. While there is still much to be done to reduce waste at the source and drive materials to higher value recycling, this demonstrates the state's leadership in supporting strong infrastructure and behaviour change around organics. The flow of food waste to organics is still significant.

Despite being at the centre of much policy and public attention, the material flow of paper and packaging is much smaller than other sectors.

Fuel use into automotive sectors represents the largest import quantity which is likely to be reduced overtime as the vehicle fleet is electrified.

While the textile and electronics sectors are interesting in their own right, they represent small material flows compared with the rest of the economy.

The following elements have not been included in the visualisation of whole of State flows:

- **an extensive energy balance** - while all fossil fuels are included in the MFA, the way the fuels distribute between sectors and end users is not described
- **water flows** – these are typically 100 times larger than the current material flows making them difficult to represent in the Sankey while maintaining the view of material flows
- **all furniture materials** – only textiles in furniture have been considered at this stage as this was a focus area of the report (a future analysis could include consumption of wood, hard plastic and metals in furniture also)
- **miscellaneous consumables** – which could be considered in an "other" category in a future analysis.

The Sankey shows the material impacts of the export economy with many of the largest flows heading out of South Australia. This makes the assessment of circularity difficult without tracking the fate of flows leaving the region.

There is also a trend for material flows to diminish across the Sankey from left to right as materials are either consumed (for example energy and food) or enter into stocks in the case of building and infrastructure. One of the challenges for the circular economy is the continued growth of the economy requiring additional material inputs that can't be supplied by material flows returning at the end of life.

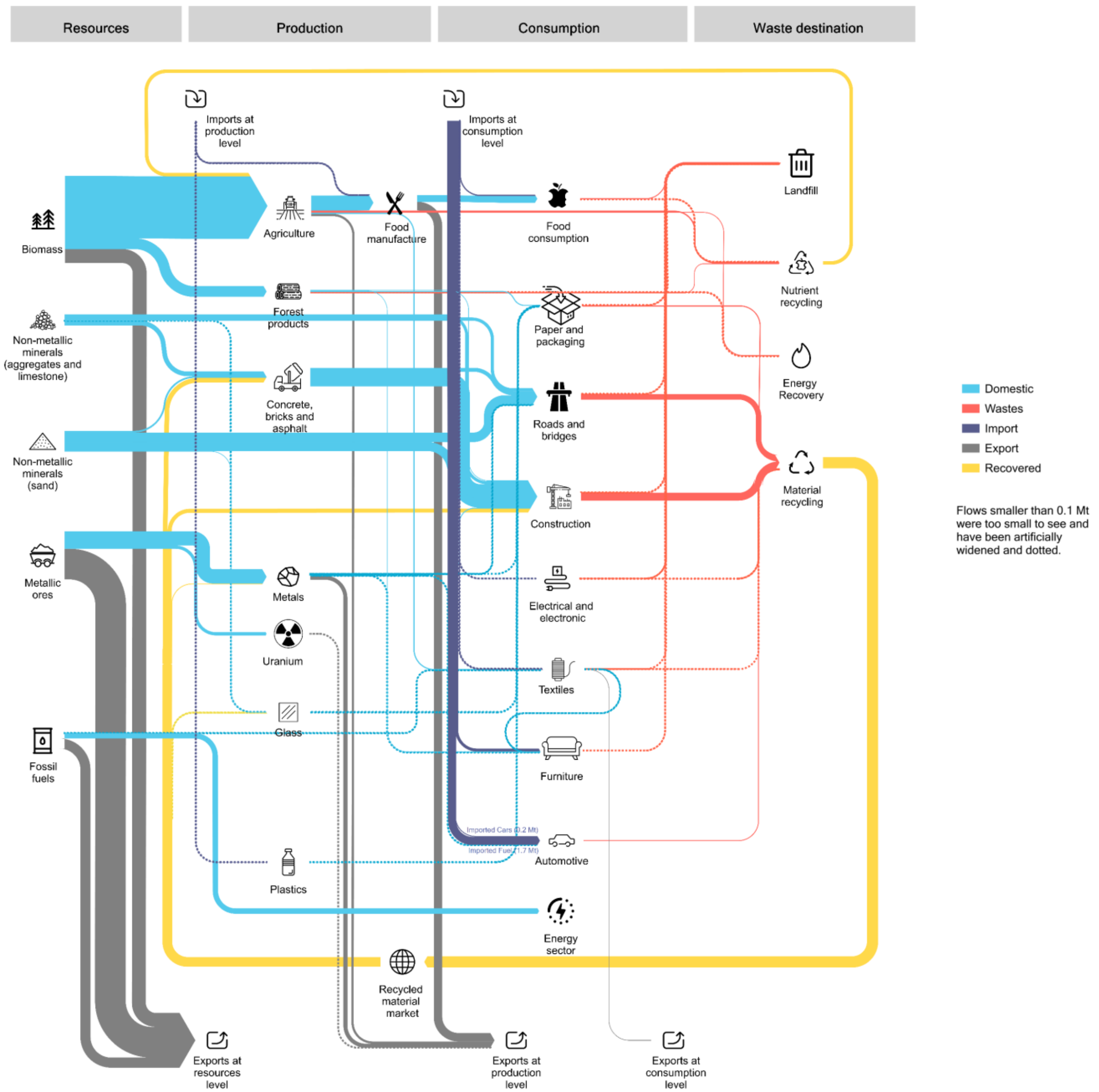


Figure 1 Material flow analysis of South Australia

# Food and organics

The 2021 update to the National Food Waste Baseline estimated that over 7.6 million tonnes of organics is wasted across the food supply chain [9]. This is a particular area of focus for Australia as the National Food Waste Strategy aims to halve food waste by 2030. While the strategy prioritises high value recovery options such as food rescue and animal feed above approaches such as composting or anaerobic digestion, it is important to recognise that there is a significant proportion of unavoidable organic waste streams which may not able to be processed through higher value diversion.

## Sector categorisation and key data sources

Organic products were characterised in two main streams: agriculture and forestry, as outlined in Table 2. These two industries are the main producers of organic material in South Australia, and both export significant amounts of material, particularly broadacre crops and raw or minimally processed commodities from forestry.

Aside from these two major economic sectors, South Australian gardens produce significant amounts of organic waste. This is included under the classification of garden waste and includes a mixture of waste sourced from households and public parks.

The recently updated National Food Waste Baseline [9] provides a detailed breakdown of plant-based and animal-based food production in South Australia, including estimates of exported fractions. The aggregated results of this analysis were used here to differentiate between plant-based and animal-based products. The distinction is necessary as the two categories of products have very different environmental impacts and reporting them separately allows to disaggregate these differences.

For waste, the selected categories were mapped to the recently completed South Australian organics sector analysis [10].

Table 2 Food and organics categorisation

| Product category | Product sub category | Examples |
|---|---|---|
| Agriculture | Plant-based | Fruits, vegetable, nuts, grains, legumes, oil crops. |
| | Animal based | Livestock, dairy products, fisheries. |
| Forestry | Construction material | Structural timber, engineered wood such as MDF or plywood. |
| | Paper | Packaging, office paper |
| | Other products supplied to commercial and industrial sectors | Miscellaneous compostable fractions from food industry (not elsewhere specified) |

## Modelling approach and assumptions

This model uses a stock and flow approach, with inputs and outputs of organic products in the economy assumed to be at equilibrium. As such, variation in the stocks of organic products in use within the South Australian economy was not considered.

The model reconciles different data sources with each signifying a distinct part of the South Australian food and organics picture. The sub-sectors representing the food and organic sector are mostly disconnected and as such could be modelled independently from each other.

The model developed to represent the agricultural sector draws upon the 2021 update to the National Food Waste Baseline conducted by Lifecycles as part of the National Food Waste Strategy Feasibility Study [9].

The updated food waste baseline model captured information at the state level whenever possible. This allowed for the extraction of information on crop and livestock production specific to South Australia, including broadacre crops, horticulture, fisheries, livestock and animal products. The model was built using a mass balance approach to assess how much food product is processed domestically, exported, imported or wasted at each stage of the supply chain up to the point of retail. From this information, the total 'apparent consumption' of food per capita was estimated and cross-checked against information reported by the Australian Bureau of Statistics [11]. The total food waste going to landfill and commercial composting was sourced from a bin audit conducted by East Waste in 2019 combined with data from the South Australian Recycling Activity Survey [7, 12] An estimate of the amount  of food waste going to waste water treatment plants (WWTP) and home composting systems was estimated from a 2019 household survey conducted prior to the update of the National Food Waste Baseline [13].

Non-food agricultural products, of which fibres used for textile manufacturing such as wool and cotton are the major constituents, were not included here as they were already considered in the textile section.

The forestry sector was modelled using statistics published by ABARES [14], with manufactured products estimated from a range of other sources [15, 16]. For the sake of readability, forest products post-manufacturing is not represented here. Figure 1 and Figure 9 provide further detail on the fates of forest products.

Another key reference used throughout the model is the recent study on organic waste conducted for Green Industries SA [10]. It provided data on specific waste streams in the food and forest product manufacturing sectors, as well as organic streams, vegetation, and garden organic waste. This includes flows both exchanged between entities and processed internally by organisations.

Food consumption was based on national statistics developed during the update of the National Food Waste Baseline [9], and cross-checked against available national statistics [11]. National values were scaled to the state of South Australia based on population, assuming that consumption patterns are similar between states.

Waste production in the supply chain of animal and plant-based products were modelled to specifically represent the commodity they refer to. After the consumption stage waste rates are aggregated across animal and plant products.

The national consumption of food products is estimated in the food waste baseline as production and import minus export. As this consumption is translated to South Australia based on population, the amount of food product that leaves the state is modelled as:

$$\textit{export} = \textit{production} - \textit{consumption} + \textit{imports}$$

Thus, food which is not part of the South Australian consumption chain is assumed to be exported.

Similarly, timber exports are estimated as the difference between production and known consumption.

Note that all numbers quoted here are based on reported organics flows and exclude informal organics processing on farms or households, for which insufficient data is available.

## Material flow results

The MFA presented in Figure 2 shows that the South Australian economy is a powerhouse in the primary production of organic commodities, with large amounts of primary commodities directed towards both interstate and international export markets. Based on the information collected, around 10% of forestry products harvested are processed and consumed domestically. In the case of food products, approximately 20% of crops grown in South Australia are processed and consumed outside the state's boundary.

By far the largest stream of organic material is feed going to livestock. South Australia's animal herds consume around 9 million tonnes of grazed biomass and a further 2.7 million tonnes of fodder.

The analysis indicates that the South Australian economy produces and manages over 1.8 million tonnes of organic waste annually. A large fraction of this waste is collected via commercial and industrial (C&I) collection systems (around 1.4 million tonnes). Only 12% of all organic waste is disposed of in landfill. The preferred method of treatment is composting and mulching for nutrient recycling, which is used to manage half of the state's organic waste stream. This management route results in the production of over 480,000 tonnes of composted material which is assumed to be reused for agricultural processes. It is worth noting that a significant amount of the original waste mass is lost as $CO_2e$ emissions to air, representing approximately 430,000 tonnes.

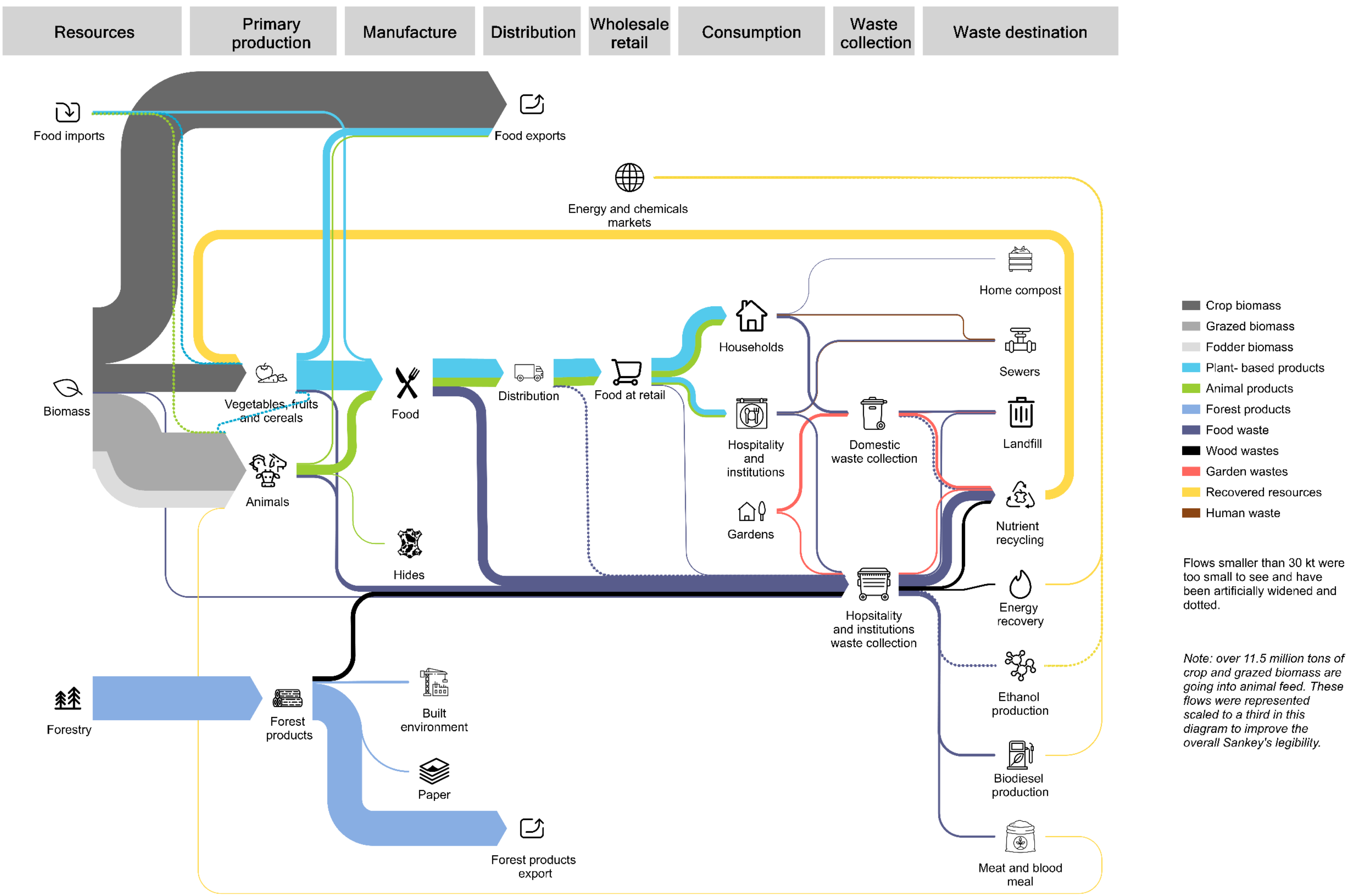


Figure 2 Material flow analysis of food and organic products

## Carbon perspective

The total embodied carbon of organic streams consumed annually in the South Australian market was estimated at approximately 8.3 million tonnes $CO_2e$. Figure 3 compares the amounts of key food and organics commodities consumed in South Australia with the embodied greenhouse gas emissions associated with their production.

The consumption of plant-based food dominates the mass of organic products consumed in the state at almost 60% of the total. However, when looking at the embodied carbon of organic products, animal-based food is the primary driver, representing 79% of total emissions for only 28% of the total mass flow at the consumption stage.

Livestock rearing, particularly in the case of ruminants like beef and sheep, results in significant emissions of methane to the atmosphere. This is linked to the animal's digestive system which relies on a process called enteric fermentation. In their digestive tracks, ruminants host micro-organisms which break down complex carbohydrates, such as cellulose, into molecules which can be absorbed into the bloodstream of the animal. A by-product of this process is methane, which is belched out. Methane emissions from livestock bear significant weight on the national greenhouse gas emissions. Data published on the Australian Greenhouse Emissions Information System [17] report that, in 2019, enteric fermentation alone represented about 15% of South Australia's state-wide greenhouse gas emissions.

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Researchers are developing methods to reduce methane emissions from enteric fermentation. A novel food supplement produced from Asparagopsis seaweed inhibits the production of methane in the cow's gut by up to 90%. This is an emerging South Australian industry, with the first commercial licences granted in January 2021 for two seaweed farms to be established on the Yorke Peninsula [18]. While at this stage the supplement can only be used in feedlots, where nutrition can be controlled, it has the potential to significantly reduce the methane emissions of livestock.

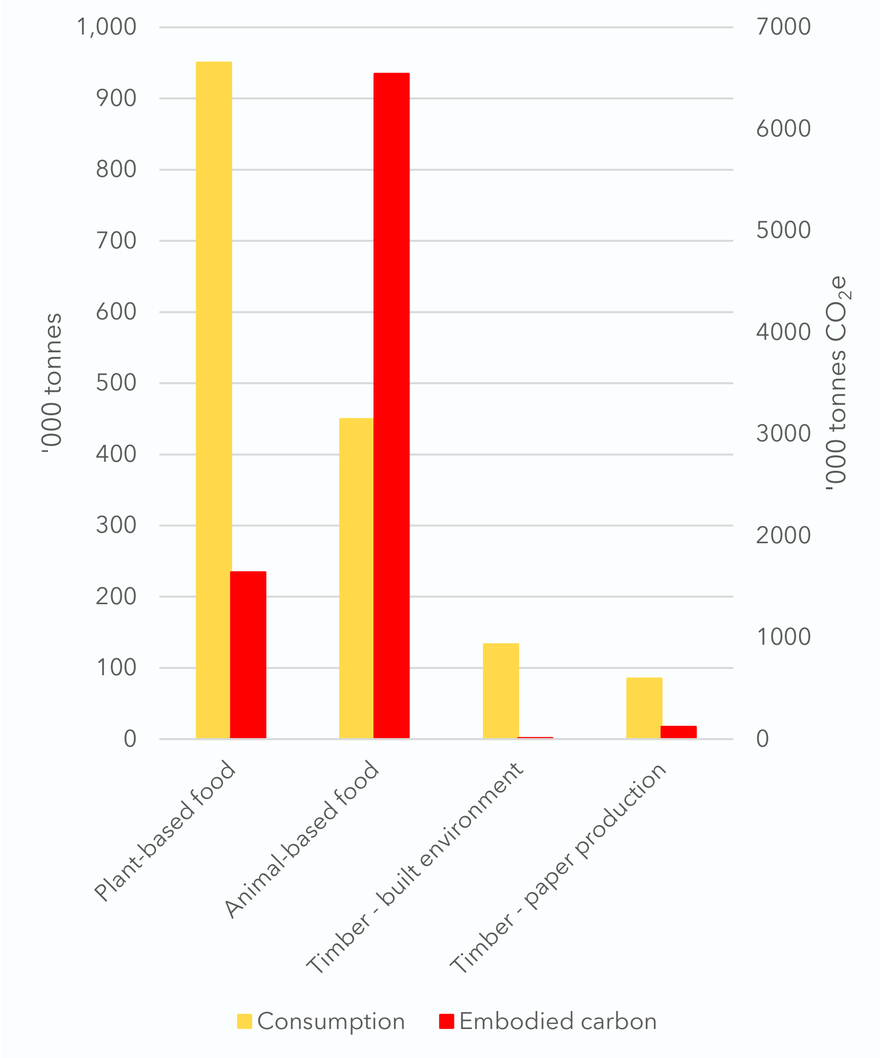


Figure 3 Comparing food and organics consumption with associated embodied carbon

South Australian exports of organic material are almost three times its local consumption. 1.8 million tonnes of timber and 3 million tonnes of agricultural products are exported. Figure 4 compares the mass exported to the embodied carbon emissions these materials represent.

While the mass of timber is significant, its embodied carbon emissions are trivial relative to food products. Raw timber's low embodied carbon and the minimal transformation of exported commodities leads to the overall embodied carbon being just over 40,000 tonnes $CO_2e$ for 1.8 million tonnes of product.

Of the 3 million tonnes of agricultural products, only 85,000 tonnes are animal-based. Plant-based foods are by far the largest exported organic commodity in South Australia, particularly wheat and barley which represent three quarters of the total. As a result, plant-based food exports are the most significant organic commodity export, both in mass and embodied carbon terms.

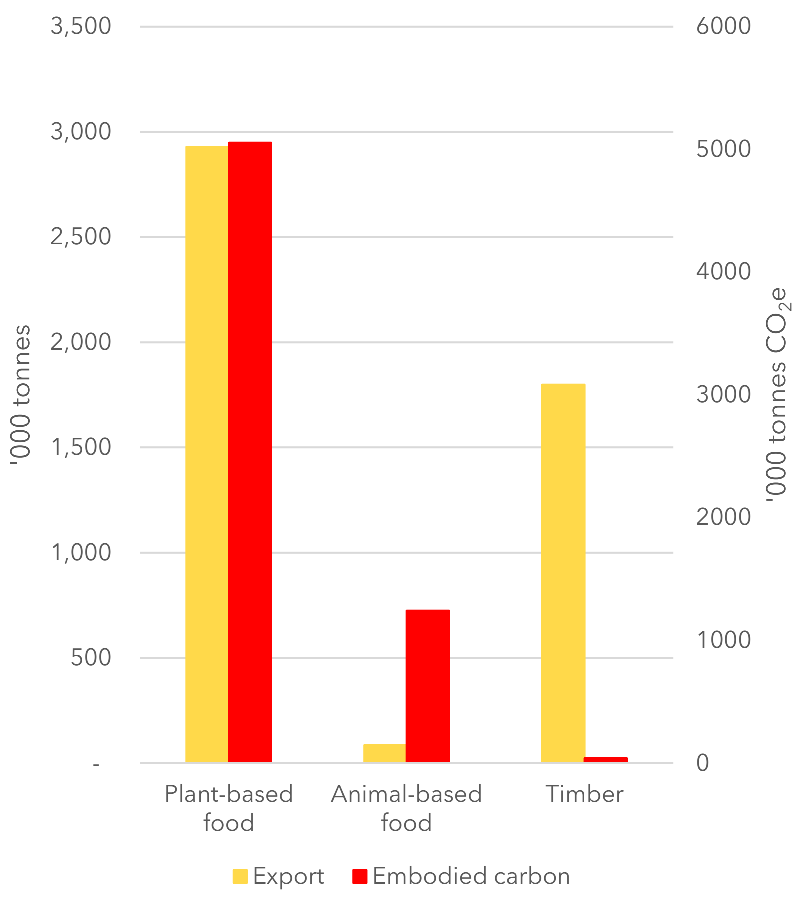


Figure 4 Comparing mass of food and organics exported with associated embodied carbon

**Waste management considerations**

Organic materials that make their way to landfill at end-of-life generate significant greenhouse gas emissions. This is because when organic matter is buried in a landfill, anaerobic conditions develop leading to the emission of methane gas as it degrades. The emissions associated with organic material discarded in landfill are 116,000 tonnes $CO_2e$ [10].

Recycling organics, including through composting, results in environmental benefits through the production of secondary materials. When organic waste is composted, material degradation occurs in aerobic conditions avoiding methane production. The output of the composting process can also be used to replace conventional fertilisers. Anaerobic digestion harnesses the reactions taking place in a landfill by creating the conditions in a closed vessel and collecting the biogas which can be used to produce energy. The process also produces a material which can be used as a replacement for conventional fertiliser due to the rich mix of nutrients in the decomposed biomass.

Recycling organic waste avoids the creation of 355,000 tonnes $CO_2e$ emissions, this is achieved through the production of secondary commodities which subsequently reduces the need to produce primary commodities [10].

Although South Australia has a very efficient management system for its organic waste, it is important to note that avoidance should be the primary target. By far the most significant emission hotspot of discarded food waste is the emissions that occur along the supply chain to produce the food itself. This was highlighted in the analysis of hotspots in the food supply chain published alongside the National Food Waste Strategy Feasibility Study [19]. The recent update of the National Food Waste Baseline [9] suggests that approximately 20% of the food purchased by Australian households will be discarded. Given that the embodied impacts of organic material are driven by food production, this suggests an opportunity to massively reduce the environmental impacts of food through addressing loss at the consumer stage.

## Nutrient flows

### Sector categorisation and key data sources

A complete analysis of the flow of nutrients associated with the South Australian agricultural sector was performed, providing an important additional environmental lens to consider in the decision-making process. Several key nutrients are necessary to life, in agricultural systems these are often artificially added as fertilisers. Among those, two of the most important macronutrients are nitrogen (N) and phosphorous (P). The MFA results were used as a basis for this analysis.

To complement the model, the amount of nutrients applied on crops as fertiliser and application losses were estimated based on Life Cycle Inventories published in Australia's national inventories database AusLCI [20].

Information required to model the flow of nutrients coming from wastewater systems was provided by SA Water.

Literature was researched and analysed to obtain other necessary information, such as the content of nitrogen and phosphorus in food [21-26], losses in the phosphorus supply chain (extraction of phosphate rocks and processing to obtain fertiliser) [27, 28], and the amount of nutrients ending up in wastewater that are not related to food (for example, from detergents and chemicals) [29].

### Modelling approach

As this model focusses on the nutrient flows of food consumed in SA, commodities produced for export were excluded, and commodities imported for domestic consumption were considered. This approach means that some of the nutrient flows captured are associated with agricultural activities located outside of the state's boundaries. Models specific to the South Australian agricultural system were used when available.

The model's starting point was the annual food consumption in South Australia. The average quantity of nutrients present in different food categories [21-24], combined with the average Australian diet [9] were used to estimate the total nitrogen and phosphorus content of the food consumed annually in the state.

The nutrient flows required to support the SA's annual food consumption were modelled backwards through the supply chain. Nutrient requirements of different crops were considered, as modelled in AusLCI [30]. Downstream modelling from the point of consumption was used to track the flow of nutrients through wastewater, composting and other waste channels ultimately to disposal and/or recovery using the MFA results to track the amount of waste going to each treatment route.

This analysis focuses primarily on the flow of nitrogen and phosphorus involved in the food cycle. All other sources of nitrogen and phosphorus which were found within the supply chain of food products, such as chemicals or cleaning products, have been grouped under one broad "other sources" category. The nutrient flows linked to animal-based and plant-based foods were modelled separately up to the consumption stage. Consumption at household and in hospitality settings were also considered separately.

#### Other assumptions

South Australian food consumption data comes from the National Food Waste Baseline [9]. Assumptions were then made regarding South Australians' diet based on the following five broad food categories:

- vegetables and legumes/beans
- fruits
- grains (cereal foods)
- lean meats and alternatives
- dairy products and alternatives (milk, yogurt and cheese) [21]

The model assumed that the consumption of these five main food categories is representative of the entire diet of South Australians, and does not consider certain food categories such as sweets, alcoholic beverages or oils.

The nitrogen and phosphorous content of different food categories was based on mapping best available data for different food products in the literature [22, 24] against our five food product categories, as shown in Table 3.

A healthy adult maintains nitrogen and phosphorus homeostasis in their body [24, 31, 32]. A few health conditions might affect this balance, but for the purpose of this analysis, it is assumed that the overall balance is maintained and that the amount of nitrogen and phosphorus that is ingested will be excreted.

The nitrogen and phosphorous values for all meat and bone meal were estimated from data on beef processing.

Losses were assumed to be evenly distributed across all food categories, and losses occurring between wastewater collection and treatment of effluents were not included.

Around 15.5% of the wastewater's nitrogen was assumed to comes from other sources, such as chemicals, cleaning products and cosmetics [29]. Phosphorus entering wastewater was back calculated from phosphorus exiting the waste water treatment plant (WWTP).

All reused effluents and compost were assumed to be applied on fields with food production as an outcome, rather than used for urban green spaces maintenance, or floriculture. Losses at nitrogen fertiliser plants were assumed to be minor and are not represented here. Phosphorus fertiliser production on the other hand is known for being inefficient and losses were calculated [27, 28].

There are important food losses at the crop level, for instance, products which were not harvested in time or damaged before the harvest. This analysis assumes that lost crops are left in the field and their nutrients returned to the soil, thus not leaving the system. Similarly, animal manures are assumed to be left on grazing fields or used on other food producing fields, hence not leaving the system. Leaching and soil erosion linked to nutrients left in the soil have been accounted for.

Table 3 Composition of food categories to determine nitrogen and phosphorus flows

| Product category | Nitrogen | Phosphorous |
|---|---|---|
| **Vegetables & legumes** | Averaged between vegetables and legumes | |
| **Fruits** | Based entirely on apples | Averaged between clementines and apples |
| **Grains** | Based entirely on rice | Averaged between whole wheat pita, whole wheat bread, corn tortillas, oatmeal and brown rice |
| **Meats** | Averaged between lean meats and eggs | Averaged between meats, eggs, and fish |
| **Dairy** | Averaged between milk and cheese | |

### Material flow results – Nitrogen

The results of the nitrogen flow analysis are provided in Figure 5.

Overall, approximately 27,000 tonnes of nitrogen enter the South Australian food consumption system every year, including both fertiliser inputs (86%) and nitrogen fixed by crops (14%).

Flows of nitrogen found in water effluents and biosolids are well managed in South Australia. 100% of biosolids and 43% of effluents are cycled back to agricultural processes, representing over 1,100 tonnes of nitrogen annually.

The total nitrogen content of solid food waste was 5,200 tonnes, with 25% of this flow cycling back to primary production systems as animal feed or compost. Landfill is still a major destination for food waste, with 53% of the nitrogen in food waste being lost to landfill.

Biological reactions in the nitrogen cycle lead to significant losses at the primary production and wastewater treatment stages of the life cycle. Approximately 56% of the nitrogen applied as fertiliser is estimated to be lost, either to air through biological reactions on field (42% of losses), or to water through run-off (58% of losses). A significant fraction of nitrogen is also lost through wastewater treatment, where over 90% of the nitrogen entering a wastewater treatment plant is released to air during the treatment, representing over 16,000 tonnes of nitrogen annually. Although these losses are linked to biological reactions which can be considered unavoidable, they have significant environmental implications – emissions of nitrogen to air influence climate change, while emissions of nutrients to water can result in eutrophication of local waterways.

The overwhelming majority of nitrogen found in the average diet comes from animal-based foods (81%). Indeed, meat has an inherently higher content of nitrogen then plant-based foods: meats such as beef and lamb contain an average of 4.48 g of nitrogen per 100g. Fruits, such as apples on the other hand contain only 0.05 g of nitrogen per 100g.

The main source of anthropogenic nitrogen is the Haber-Bosch process, which consumes high levels of energy. Reusing more nitrogen from current waste could provide significant environmental benefits by reducing the need for the industrial production of additional flows of nitrogen to balance the loss.

### Material flow results – Phosphorous

The results of the phosphorous flow analysis are provided in Figure 6.

The flows of phosphorus associated with food consumption in South Australia are equally distributed between animal-based and plant-based products.

Phosphorus cycles back to primary production systems through the efficient use of biosolids from wastewater treatment plant. Indeed, phosphorous has a low water solubility, and is not gaseous under standard conditions. This means that 90% of phosphorous entering wastewater are reused at the start of the food production cycle. This is enabled in South Australia by regulation enabling biosolid reuse.

Additionally, food waste recovery through composting, or as animal feed allows, to cycle a part of the phosphorous found in the system back to primary production processes. The estimated amount of phosphorus in food waste was just over 800 tonnes, 56% of which is reused as animal feed, or composted and applied back on field. Approximately 250 tonnes ended up in landfill, with the remaining 13% of phosphorus in food waste ending up in WWTPs.

However, our analysis shows that 64% of all phosphorus going into crops is not used by crops but stays in the ground, while another 21% is lost through leaching and soil erosion [33]. The distinction here is meaningful because the phosphorus that stays in agricultural soils can be used by future crops [34]**.** On the other hand, the presence of excess phosphorus in water can cause a nutrient imbalance resulting in eutrophication. Eutrophication is a significant environmental burden as it encourages algal growth at the water's surface, depriving the water and other organisms of vital oxygen.

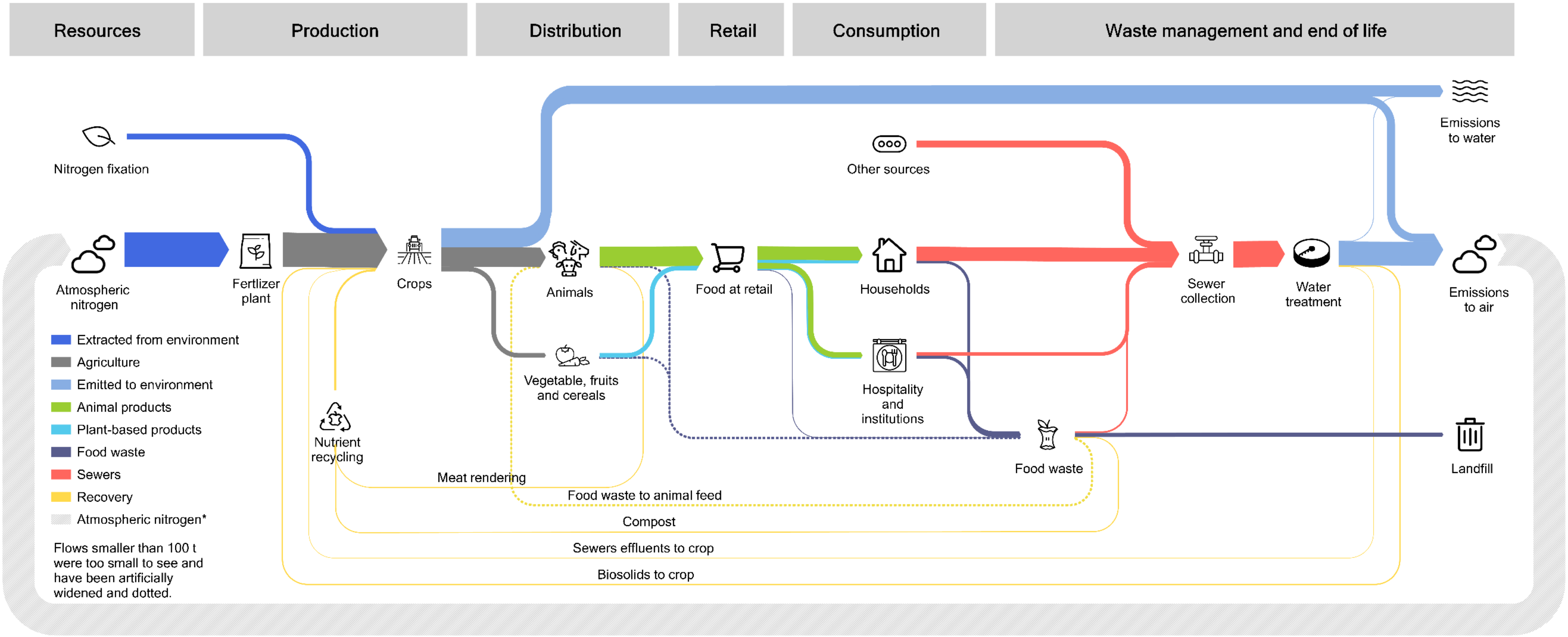


Figure 5 Nitrogen flow analysis of food and organic products

* The flow from "emissions to air" to "atmospheric nitrogen" illustrates that nitrogen is essentially drawn from the same pool into which it is emitted. This flow is not considered 'circular' as atmospheric nitrogen extraction requires energetic industrial process.

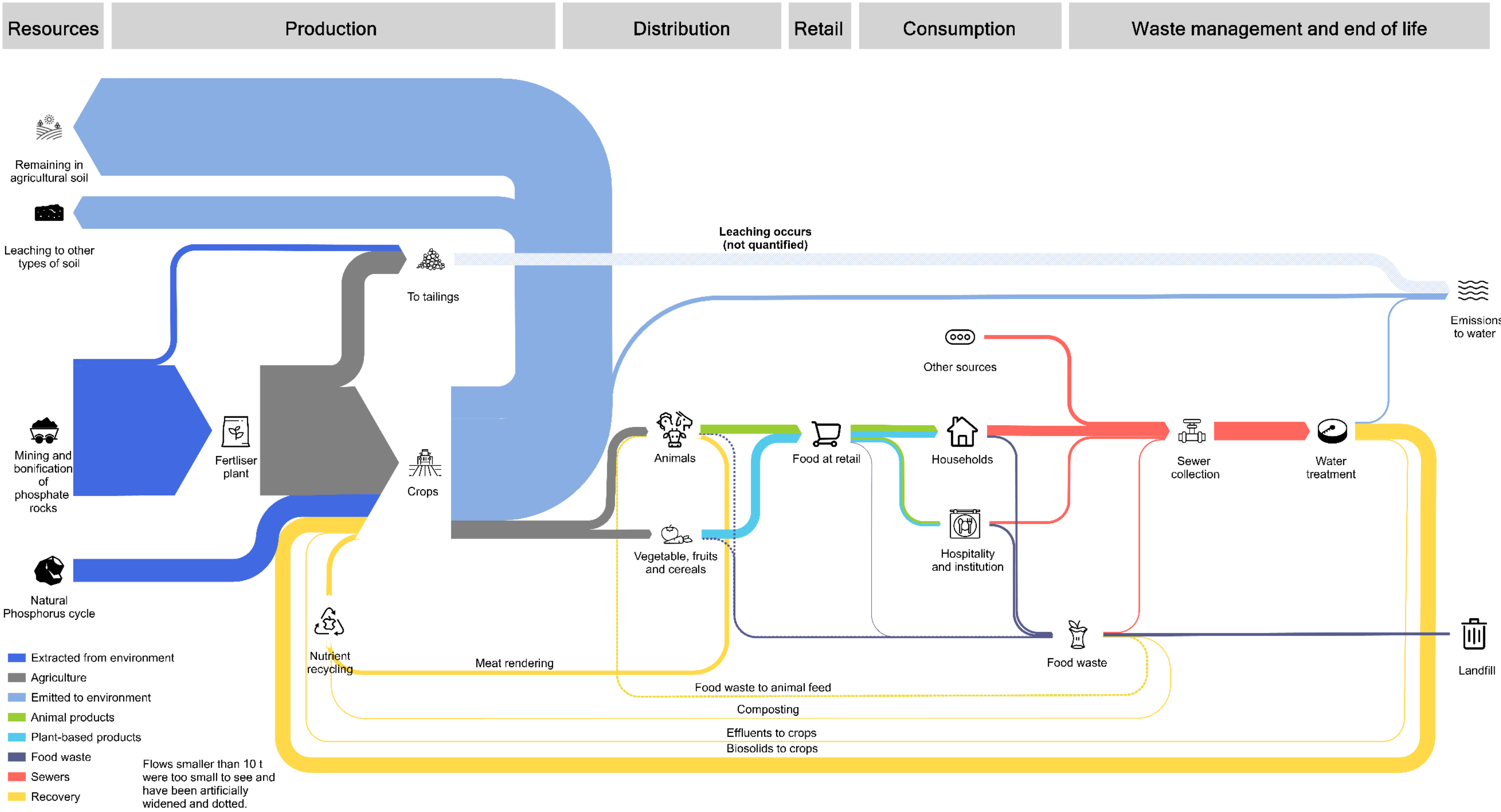


Figure 6 Phosphorus flow analysis of food and organic products

## Circularity score

The circularity score provides a snapshot of the current level of circularity, based on the data presented in the Sankey diagrams. Of the two indicators considered, neither were initially designed for biological materials. In 2019, the Material Circularity Indicator methodology was revised to include an approach to modelling the circularity of biological materials. However, this method is not well suited to materials which get consumed such as food. For this reason, the circularity of the food and organics sector has been determined using the nitrogen flows modelled.

Of the total nitrogen entering the cropping system, 9% comes from recovered sources such as compost, WWTPs, meat rendering, biosolids to crops, and food waste to animal feed. Because the system is a closed loop, meaning that all outputs eventually become inputs, 9% of the nitrogen outputs at the end-of-life stage are recovered. This results in an MCI of 0.18 and an NCM of 9%, as shown in Table 4.

It should be noted that the food and organics waste that is recovered in South Australia is very high. However, from a nutrient perspective, there is leakage throughout the system, resulting in a lower circularity score.

There is potential to improve the circularity of nitrogen within the food and organics sector through increased recovery of wastewater from treatment plants. One opportunity for a more systemic change might be the introduction of urine-separating toilets, especially in public amenities at parks and recreation areas where the nitrogen can be utilised.

Table 4 Circularity metrics for food and organics sector (nitrogen flows)

| Category | | Score |
|---|---|---|
| **Circular inputs (feedstock)** | Feedstock reused content | 9% |
| | Feedstock recycled content | - |
| | Recycling efficiency | - |
| | **Circular inputs** | **9%** |
| **Circular outputs (end of life)** | EOL to reuse | 9% |
| | EOL to recycling | - |
| | Recycling efficiency | - |
| | **Circular outputs** | **9%** |
| **MCI** | | **0.18** |
| **NCM** | | **9%** |

# Electronics

The increased use of electronic devices has made e-waste the single fastest growing waste stream globally [35]. Between 2014 and 2019, the global annual generation of e-waste rose from 44.4 million tonnes to 53.6 million tonnes – and is expected to increase to 74.7 million tonnes by 2030 [36].

For the purpose of this report, 'electronics' refers to electrical and electronic equipment that is dependent on electric currents or electromagnetic fields to function. The term e-waste is used to signify electronics at end of life, and includes components, subassemblies and consumables which are part of the original equipment at the time of discarding.

### Sector categorisation and key data sources

The hundreds of different types of electronics entering South Australia's economy were classified into clearly defined product categories for modelling and interpretation purposes.

The modelling methodology was based on the 54 product categories listed in the *United Nations University Statistical Guidelines* (UNU-Keys) [37]. The UNU-Keys provide a framework to develop detailed statistical data, which can then be aggregated to a meaningful level.

The aggregated product categories used in this report are based on an adaptation of the e-product stewardship evidence report recently released by the Department of Agriculture, Water and Environment [38], as shown in Table 5. This classification takes into account the six categories used in the European Union Waste Electrical and Electronic Equipment Directive [39], specificities around the management of certain e-wastes in Australia and strategic areas for the South Australian economy.

Table 5 Electronics categorisation

| Product category | Examples | Difference with national approach |
|---|---|---|
| **Solar PV and battery storage** | PV systems, and power storage, including household, commercial and utility-scale systems | No difference |
| **TV, computing and mobile phone equipment** | Televisions and computers, including printers, computer parts and peripherals (as covered by the scope of the NTCRS)<br>Mobile phones, their batteries, chargers and accessories (as covered by MobileMuster) | Considered as two separate streams in the national report. These were aggregated for SA due to similarities in management and characteristics. |
| **Lighting equipment** | Light-emitting diodes (LEDs), fluorescent tubes, lamps | No difference |
| **Large household appliances** | Washing machines, dryers and dishwashers | No difference |
| **Temperature exchange equipment** | Fridges, freezers and air conditioning | No difference |
| **Handheld batteries[2]** | Batteries under 5 kg, as defined by the Battery Stewardship Council [40] | Category not included in national report (out of scope) |
| **Battery electric vehicles** | Batteries from fully electric vehicles (hybrid and conventional cars are excluded) | Category not included in national report (out of scope) |
| **Other small equipment** | Kettles, toasters, vacuum cleaners, electric toothbrushes and musical instruments | No difference |
| **Other large equipment** | Professional equipment, leisure equipment | No difference |

[2] Lead acid batteries are excluded to focus on the importance of recycling other battery types as (i) the sheer mass of lead acid batteries far outweighs any other chemistry [40] and (ii) while over 95% of lead acid batteries are currently collected and recovered, only 12% of alkaline and 6% of lithium ion batteries are currently recycled [40].

## Modelling approach and assumptions

The model uses a stock and flow approach. The electronics sector is extremely dynamic, with rapid uptake of new products and mixed lifespans between product categories. This means that the breakdown and mass of products entering the market on any given year will not be representative of the waste arising in that year.

The stock and flow approach uses historical estimates of products entering the market, and their probability of failure over time to estimate the amount of products leaving the market as waste every year. It can also be used to model the stock of products in use in the economy during the year. The methodology applied here was formalised by the UNU [37].

The breakdown of material coming out of each product category (Table 6) was defined from published literature [41-48] and past studies conducted by Lifecycles [49-51].

Solar PV and battery storage were modelled based on capacity installed in South Australia [42, 52, 53]. The state has been leading the country in the rate of installations per capita, which meant that scaling based on national data could present significant inaccuracies. The amount of handheld battery waste was estimated from a recent national MFA [40], the results of which were scaled to South Australia based on population.

For all other product categories, domestic production was assumed to be negligible. South Australia's apparent consumption was estimated as Australian imports minus exports, scaled to South Australia based on population. This is in line with the literature [42, 52, 53], as well as work conducted in Victoria [54] and international guidelines [37].

Table 6 Material breakdown in electronics

| Product category | Plastic | Non-ferrous metal | Ferrous metal | Precious metal | Specialty metal | Glass | Other |
|---|---|---|---|---|---|---|---|
| Solar PV and battery storage | 6.5% | 18% | 10% | 0.057% | 0.022% | 65% | 1.1% |
| TV and computing equipment | 21% | 5.1% | 57% | 0.00307% | 0.00051% | 11% | 6.3% |
| Lighting equipment | 15% | 9.5% | 54% | 0.0017% | 0.012% | 4% | 18% |
| Large household appliance | 10% | 3.2% | 61% | 0.0011% | 0.00069% | 4% | 21% |
| Temperature exchange equipment | 15% | 4.7% | 67% | 0.0021% | 0.0013% | 4% | 10% |
| Handheld batteries | 3.0% | 21% | 42% | 0% | 1.12% | 0% | 33% |
| Battery electric vehicle | 18% | 12% | 58% | 0.0056% | 0.50% | 4% | 7.5% |
| Other small equipment | 14% | 11% | 53% | 0.0014% | 0.00086% | 3% | 19% |
| Other large equipment | 12% | 3.2% | 65% | 0.0014% | 0.00083% | 4% | 15% |

End-of-life management was assumed to be split between three options: high efficiency recycling, low efficiency recycling, and landfill.

High efficiency recycling refers to processes that start with dismantling or separation to direct the various component and material fractions to specialised recyclers. These are typically used for TV, computing and mobile phone equipment - for which recyclers have high recovery rate targets under the National Television and Computer Recycling Scheme (NTCRS), and results in a high rate of material recovery.

Low efficiency recycling covers processes where entire appliances are shredded to separate the ferrous and non-ferrous metal fractions. The remaining fraction (the 'flock') is sent to landfill.

The latest South Australian Recycling Activity Survey [7] was used to characterise flows of e-waste going to high efficiency recycling processes. These waste streams are typically managed through a product stewardship scheme which collects and publishes data on collection amounts (e.g. batteries, computers, TVs, mobile phones and lighting equipment), and hence the collection data is well characterised. The pathways for e-waste going to low efficiency recycling processes are less clear. A 2014 analysis on the end-of-life management of refrigeration equipment [55] was used to model the fraction of large equipment waste going to metal scrappers.

South Australia has had a landfill ban on all e-waste since 2013. In the absence of information on the actual impact of this ban on the management of e-waste, it is assumed that only 50% of e-waste for small equipment and lighting equipment is collected for shredding, as these smaller products are still easily placed in household rubbish bins. This same assumption was used to model solar PV and battery storage, for which high-efficiency recycling processes are still in their infancy.

High efficiency recycling was assumed to recover 95% of the material in e-waste, in line with data published by the four NTCRS co-regulatory agreements [56-59] and MobileMuster [60]. In the case of low efficiency recycling, it was assumed that 90% of metals would be recovered, and the shredder flock would be disposed of in landfill.

Raw material requirements were calculated based on the material extraction required to obtain one unit of a commodity. Many of these factors were based on the European handbook on economy-wide material flow accounts [61] or on national life cycle inventory data [62]. For instance, in the case of ferrous metal, approximately 2.3 kg of ore must be extracted to produce 1 kg of metal, while over 150,000 kg of raw material must be extracted to produce 1 kg of precious metal. This is strikingly visible in the electronics Sankey diagram (Figure 7) where large arrows of raw materials feed the manufacturing processes associated with the production of the different product categories, to the point that the flow of precious metal ore could not be shown on the Sankey diagram as it would result in all other flows becoming invisible.

## Material flow results

The MFA results for the electronics sector are provided in Figure 7.

The total amount of electronics entering the South Australian economy in 2019 is estimated at 80,000 tonnes. This flow is driven by solar PV and battery storage installation in the state, representing more than 34,000 tonnes of product. Other streams of significance include temperature exchange equipment (15,000 tonnes), large household appliances (9,700 tonnes) and other small equipment (8,600 tonnes).

The estimated stock of electronics in-use in 2019 amount to 686,000 tonnes, almost 390 kg per capita. By far the largest streams of in-use products are temperature exchange equipment (172,000 tonnes) and solar PV and batter storage (136,000 tonnes).

Ferrous metals make up the largest material fraction of all electronics, representing close to 50% of the products in-use, followed by glass at 16% of the entire flow. The level of uncertainties associated with the composition of electronics is highlighted by the fact that 13% of the stream was characterised as 'other', which in many cases represented the unknown in the material fractions.

Interestingly, there is a shift in the material composition of electronic products linked to the massive uptake of solar PV and battery storage products. This means that glass is becoming a much more significant fraction of material in electronics, representing 30% of the mass of electronics having entered the market in 2019. As a result, ferrous metal is becoming less significant, representing 39% of electronics purchased in 2019.

The second-hand market stream is based on high-level estimates of sales in the charity sector [63], scaled to represent the entire second-hand sales market. In this analysis, it was assumed that high-value household products are the most likely to reach the second-hand market. These includes temperature exchange equipment, large household appliances and TV, computing and mobile phone equipment.

The total e-waste arising in South Australia in 2019 is estimated at 39,000 tonnes, or 22.4 kg per capita. This is in line with other recent studies reporting on e-waste in Australia[3].

Thanks to the product stewardship schemes in place, TVs, computing and mobile phone equipment benefit from waste management systems with high recovery rates. This redirects almost 50% of the waste stream to the global commodity market feeding the manufacture of these products. It is worth noting here that materials other than metals are often downcycled, and will therefore not make their way back into high value products such as electronics. For instance, much of the glass recovered from electronics is used as an input in concrete manufacturing rather than recycled as glass. A similar story can be told with plastics, as the wide range of polymer types found in electronics make separation into high grade single polymer streams particularly complex.

Information on temperature exchange equipment suggests that up to 90% is collected via formal (e.g. take-back schemes, council pick-up) and informal schemes (e.g. hard-rubbish scavenging) and directed to metal scrapping facilities [55], though available data does not allow to disentangle the percentage collected through the different pathways. These products are then shredded to separate the ferrous and non-ferrous metal fractions and sold to the global commodity market. The flock, which is the non-recovered fraction after shredding, is discarded in landfill. It is worth noting that the same metal scrapping companies operate as the second tier in the recycling system of TV, computing and mobile phone equipment – the difference being that these products are disassembled first, and only metal parts are sent to the metal scrappers. This allows an increase in recycling efficiency by avoiding the creation of large amounts of shredder flock that can only be discarded in landfill.

[3] The Global E-Waste Monitor estimated 21.3 kg of e-waste produced annually capita in Australia and New Zealand, and the recent national study estimated the Australian e-waste generation at 20.4 kg per capita.

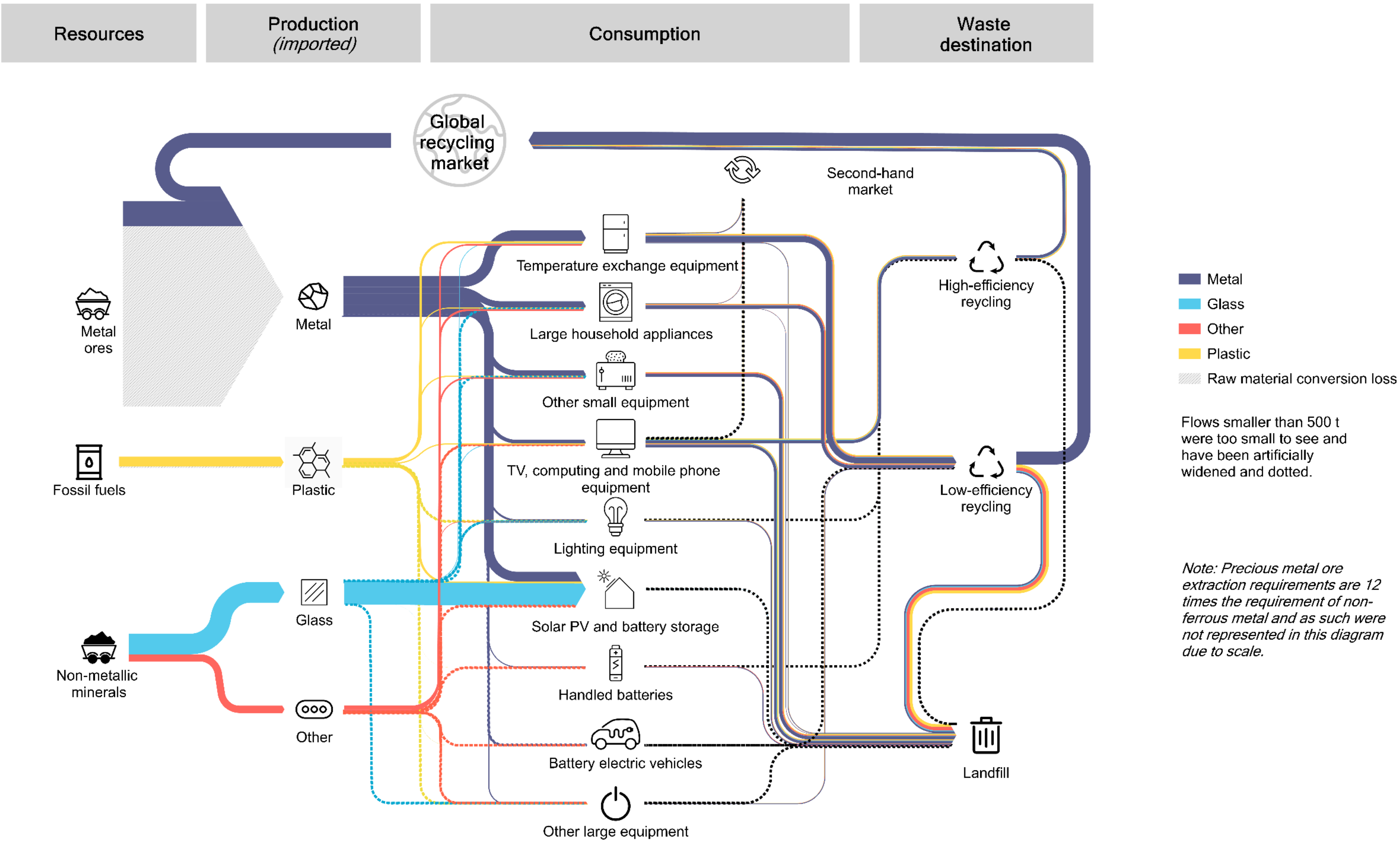


Figure 7 Material flow analysis of electrical and electronic equipment

Of the total stream, approximately 13,700 tonnes of South Australia's e-waste is sent directly to landfill (35% of the total). This increases to 22,300 tonnes (57%) when accounting for inefficiencies in reprocessing.

An estimated 21,100 tonnes of e-wastes are directed to low efficiency recycling processes (54% of total) and 4,600 tonnes to high efficiency recycling processes (12% of total). Both process types have inherent inefficiencies resulting in some level of loss, which results in additional waste going to landfill, as mentioned above.

The most significant streams are small equipment (10,000 tonnes); temperature exchange equipment (9,100 tonnes); TVs, computing and mobile phone equipment (8,500 tonnes); and large household equipment (5,300 tonnes).

The analysis shows a significant build-up of stocks in the home power and storage category, driven by the uptake of solar PV in South Australia since 2010 (following the introduction of solar feed in tariffs in 2008), and particularly given the level of constant growth observed since 2015. South Australia leads the country in the uptake of solar PV by households, with 40% of homes having solar installed while the national average stands at 27% [64].

With the average lifespan of PV panels ranging from 20 to 30 years, the amount of PV installations reaching end-of-life is currently low compared to that entering the stock. This means that South Australia can expect a significant flux of PV systems coming out of the economy by 2030.

Anecdotal evidence suggests that the amount of PV systems being discarded may be underestimated, with reports suggesting that panels may be replaced before their end-of-life for higher capacity systems, with old panels typically being discarded even though they could still be used [65]. This suggests the potential to develop a second-hand market for solar panels, which could be explored further by Green Industries SA as a way to cope with the expected growth in this waste stream. Additionally, educating users on the proper maintenance of PV systems to increase the lifespan of the product is another aspect which could be explored, as faults can otherwise go undetected until system failure.

While some manufacturing of electronics takes place in South Australia, reliable data on domestic production was not available for inclusion in the modelling. Better understanding local production could warrant further research to improve the data, as well as understanding these important local stakeholders in the electronics value chain.

## Carbon perspective

Climate change impacts occur at every step of the product life cycle. While the priority has been on creating more energy efficient products to reduce energy consumption – and greenhouse gas emissions – during use phase, the manufacturing of e-products is also a significant contributor. Extending product life and recycling materials can recoup some of these embodied emissions.

For this report, the greenhouse gas emissions associated with the supply chain of e-products, referred to as 'embodied greenhouse gas emissions', was modelled across all product categories at different life cycle stages and for different materials.

The total embodied carbon in electronic products entering the market was estimated as 725,000 tonnes $CO_2e$, with the largest embodied carbon flows linked to solar PV and battery storage equipment (273,000 tonnes $CO_2e$); temperature exchange equipment (120,000 tonnes $CO_2e$); and TVs, computing and mobile phone equipment (130,000 tonnes $CO_2e$).

The embodied carbon associated with material contained in electric and electronic products represent only a part of the total greenhouse gas emissions associated with these products. Of the embodied carbon of products discarded in 2019, approximately 35% is linked to material extraction and processing. The remaining 65% of emissions are associated with all other steps, such as manufacturing processes and transport. The balance between materials and other supply chain contribution to embodied carbon varies according to the product category, as shown in Figure 8.

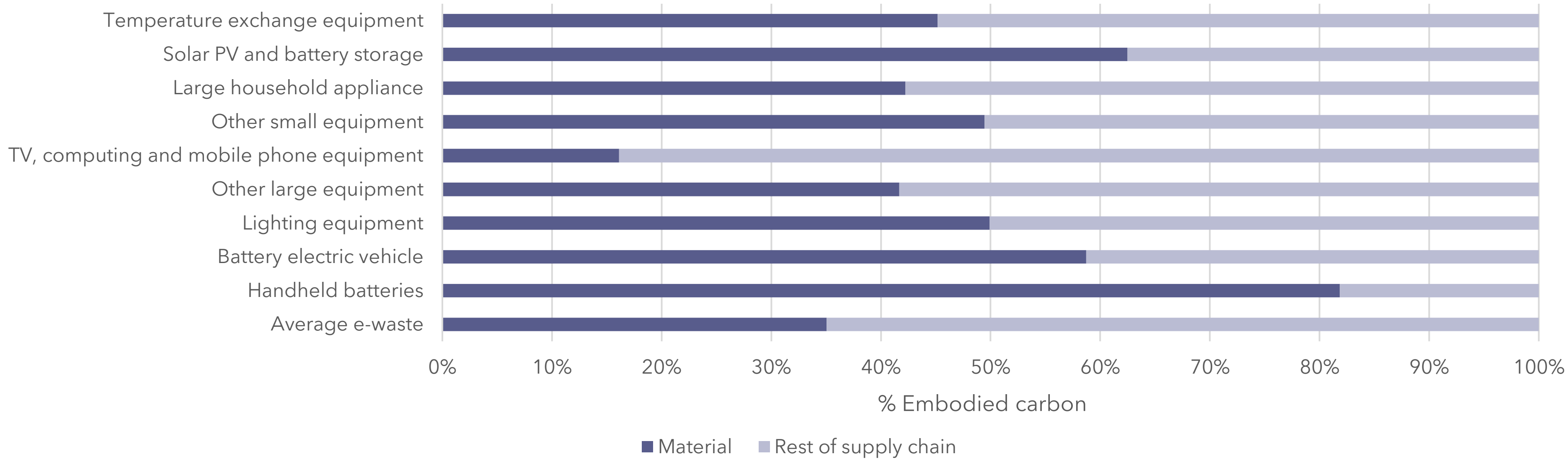


Figure 8 Source of embodied carbon in electronic products.

When a product reaches its end-of-life, only the embodied carbon associated with producing the different materials can be recovered through recycling processes. Inevitably, the emissions invested in other parts of the supply chain are lost when they become waste. This means that even with a relatively high level of collection for important product categories such as temperature exchange equipment, large household appliances and TVs, computing and mobile phone equipment, most of the embodied carbon in e-waste is lost.

This highlights the potential environmental benefits associated with keeping products in use in the economy for longer, with improved maintenance and affordable repair being potential approaches to lengthen the lifespan of products.

This analysis excludes the use phase of these products' life cycles. Multiple aspects will affect the significance of greenhouse gas emissions associated with product use, including the energy requirements of appliances, their use patterns and average lifespan, and the evolution of greenhouse gas emissions associated with grid electricity.

Despite the significant decrease in the carbon intensity of grid electricity [68, 69], greenhouse gas emissions associated with the use phase of electronics is still represents an important hotspot of greenhouse gas emissions over a product's life cycle for long lasting and energy intensive appliances and temperature exchange equipment. For example, a 2016 report analysing trends in whitegoods energy efficiency suggested that the annual electricity consumption of a fridge purchased in 2014 was 453 kWh [70]. This result in at least 6,700 kWh of electricity consumed over the fridge's 15-year lifespan. Considering the known evolution of the grid between 2014 and 2021, and assuming similar grid improvement trends to continue, the greenhouse gas emissions of the entire use phase are over 2,700 kg $CO_2e$ for the average fridge purchased in 2014. The embodied emissions associated with manufacturing and supply of this product are relatively minor at just over 700 kg $CO_2e$ per fridge. This underlines the importance of energy efficiency requirements for addressing climate change or this type of equipment.

This is not necessarily true of all appliances. For example, mobile phones are now so energy efficient that a recent life cycle assessment of the iPhone 12 concluded that the use phase only represents 14% of the embodied carbon [71]. Other products, such as photovoltaic systems produce electricity rather than consume it, which means that their use phase is carbon positive.

Improvements in the energy efficiency of electronics means that in some instances a replacement could be desirable, rather than keeping all products in the economy at all costs [72]. For instance, incentivised gradual phase-out of low efficiency products replaced with highly efficient products could deliver environmental benefits over the long run. The break-even point at which replacing products becomes preferable to extending their lifespan should be considered in more detail for specific product categories.

Overall, the greenhouse gas emissions associated with managing South Australian e-waste were estimated at 4,000 tonnes $CO_2e$, or 0.1 kg $CO_2e$ per kilogram of waste. The greenhouse gas emissions abated through material recovery at recycling were estimated as 64,000 tonnes $CO_2e$.

On average, the greenhouse gas emissions invested in managing and reprocessing waste paid off, with 15 tonnes $CO_2e$ avoided for every tonne of $CO_2e$ emitted during waste processing. This shows the benefits of recycling e-waste at end-of-life.

Although recycling is limited to recovering raw commodities, the benefits of recycling e-waste is clear when the production of waste cannot be avoided. However, as outlined earlier, materials only represent 35% of the greenhouse gas emissions associated with electrical and electronic equipment manufacturing. As products reach their end-of-life, only the embodied emissions linked to material inputs can be recovered. This highlights the true value of avoiding waste and retaining products in the economy by extending product lifetime through maintenance, reuse and repair practices.

## Circularity score

This baseline assessment indicates that the electronics sector in South Australia is 24% circular according to the NCM, with an MCI of 0.46, as outlined in Table 7.

The results show that reuse (both on the input and output sides) is underutilised compared to recycling. Reuse of products and components maintains more value than recycling and could be a focus of future developments in circularity within the electronics sector.

Table 7 Circularity metrics for electronics sector

| Category | | Score |
|---|---|---|
| **Circular inputs (feedstock)** | Feedstock reused content | 0% |
| | Feedstock recycled content | 24% |
| | Recycling efficiency | 85% |
| | **Circular inputs** | **24%** |
| **Circular outputs (end of life)** | EOL to reuse | 9% |
| | EOL to recycling | 65% |
| | Recycling efficiency | 66% |
| | **Circular outputs** | **74%** |
| **MCI** | | **0.46** |
| **NCM** | | **24%** |

# Built environment

Globally, buildings use approximately 40% of all resources [73], and waste from the construction and demolition (C&D) sector accounts for 44% of the total waste generated in Australia [74]. Nationally, this sector has seen a significant increase in a focus on recycling over the last few years, and as a result, has relatively high recycling rates. However, waste generation is also increasing, with a 61% increase nationally since 2006-2007 [75].

For the purpose of this report, the 'built environment' refers to all human-made structures which are used by people to live and work. Waste produced from the built environment is synonymous with 'construction and demolition waste', and includes streams such as wood, concrete, rubble, and glass.

## Sector categorisation and key data sources

The built environmental material flows have been broken down into six main sub-sectors as described in Table 8.

The material input flows for the residential and non-residential categories were calculated from current housing and non-residential construction data collected from the Australian Bureau of Statistics (ABS) [76], average floor areas of different building types [77], and from the material flow per construction type described in a study of Australian construction undertaken by the federal government in 2005 [16].

For material input flows associated with roads and bridges, the primary source of data was a study conducted by Lifecycles for the City of Charles Sturt [78]. The typical materials used in construction of one lane kilometre of road were sourced from the ecoinvent database [79]. Data for the total lane kilometres constructed in South Australia were sourced from the Australian Infrastructure Statistics Yearbook 2020 [80].

For other civil infrastructure, it was assumed that this would mostly consist of water and wastewater infrastructure. As such, data from a study for Yarra Valley Water in eastern Melbourne areas have been used [81]. The data were extrapolated to the equivalent number of households in Adelaide compared to those within the Yarra Valley Water catchment. Ports and railways are currently excluded from the analysis.

Table 8 Built environment categorisation

| Sector category | Examples |
|---|---|
| Residential - dwellings | Separate dwellings such as houses and multi-unit dwellings such as apartments |
| Residential - home improvement | Alterations, additions to existing homes |
| Non-residential | Shops/commercial offices/government buildings |
| Roads and bridges | Roads and bridges |
| Other civil infrastructure | Water pipes and other infrastructure |

## Modelling approach and assumptions

The model uses a stock and flow approach, which allows for the differentiation of the raw materials from the end-of-life flows. In the case of the buildings sub-sector, the stock accumulation was estimated as the difference between the inputs flows and waste arising. For roads, bridges and other civil infrastructure, the stock accumulation was calculated based on the annual economic growth rate and estimated lifetime of the infrastructure. Any remaining flows that could not be attributed to waste or stock accumulation were assumed to be left in ground. While the additions to stocks are likely to change over time as building practices, lifetimes and materials evolve, this analysis is a snapshot based on available data and does not account for these dynamics.

The key data sources described previously cover the consumption of materials by the six sub-sectors within the built environment.

To estimate the raw material requirements, the consumption values were adjusted using data from the AusLCI inventory [30]. It was assumed for every kilogram of forestry products produced, 3kg of timber is grown, and that aggregate, and sand extraction is equal to consumption.

For end-of-life, the materials leaving each of the six sub-sectors were mapped to one of four destinations: landfill, recycling, stock accumulation, or left in ground. The 'left in ground' destination only applies to roads and other civil infrastructure, and refers to clean fill materials such as soil, sand and rubble that is left in ground at the end-of-life of the infrastructure.

The flows to landfill were calculated by obtaining the total flows of each material to landfill from the National Waste Report [74] and allocating these flows among the six sub-sectors. This allocation was based on the distribution of the material's use between the sub-sectors. For example, if residential construction consumed 50% of all concrete in the built environment, 50% of the concrete entering landfill was attributed to the residential sub-sector. A similar approach was taken for recycling of materials, with total flows obtained from the South Australia Recycling Activity Survey [7].

The categorisation of materials differs between sources, so some materials are mapped to different categories on the input and output sides.

Several further assumptions were made regarding the built environment model, including the following key assumptions:

- Roads are replaced every 25 years.
- Water and wastewater infrastructure is replaced every 50 years.
- South Australia has an annual growth rate of 0.78% (based on population growth).
- Losses occur during the recovery of materials. These vary between materials: asphalt (5%), metals (5%), timber (10%), bricks (10%), concrete (10%) and rubble (20%).

While flows between each built environment sub-sector and waste destinations may occur either on-site during construction or at end-of-life, they are not distinguished in the data.

## Material flow results

The MFA results for the built environment are provided in Figure 9.

Construction and demolition waste in South Australia feeds into a mature recycling market. This is thanks to landfill disposal costs (particularly weight-based waste levies) that have facilitated significant investment in construction and demolition (C&D) recycling [82]. Along with other policies, programs and initiatives, a considerable amount of building waste is diverted from landfill in South Australia. The built environment MFA shows that in total 159,000 tonnes of material are sent to landfill and 2,474,000 tonnes are recycled.

During the recycling process, some losses occur, and hence 2,132,000 tonnes of recovered materials are produced annually. Of these materials, most are recycled into lower quality materials (such as concrete into aggregate). However, it is assumed that bricks collected for recycling are reused for their original function. For civil infrastructure, some material is also 'left in ground'. This includes inert materials such as sand, soil and rubble, which are used to fill areas that were excavated. The analysis shows that 1,675,000 tonnes of material are left in ground, mostly from the replacement of roads and bridges.

In each of the consumption categories, there is more material going in than there is coming out. This is because a portion of input materials go towards increasing the total stock of buildings. Approximately 5,878,000 tonnes of materials are added to stocks annually. The stock accumulation is more evident in the building sectors than in the civil infrastructure sectors.

Of the sectors included, roads and bridges consume the most materials (3,564,000 tonnes), followed by non-residential construction (2,712,000 tonnes), residential construction (2,661,000 tonnes), home improvement (725,000 tonnes) and other civil infrastructure (524,000 tonnes). The largest input material flows overall are sand (4,014,000 tonnes), concrete (3,480,000 tonnes) and aggregates (1,424,000 tonnes). It should be noted that larger flows do not necessarily correspond with larger environmental impacts. The following carbon perspective section will examine the MFA results through a climate change lens.

The MFA can be further improved by targeting specific areas for more focused data collection. For the built environment sector, it is recommended that actions be taken to gain a better understanding of the use of reused and recycled materials in the construction market.

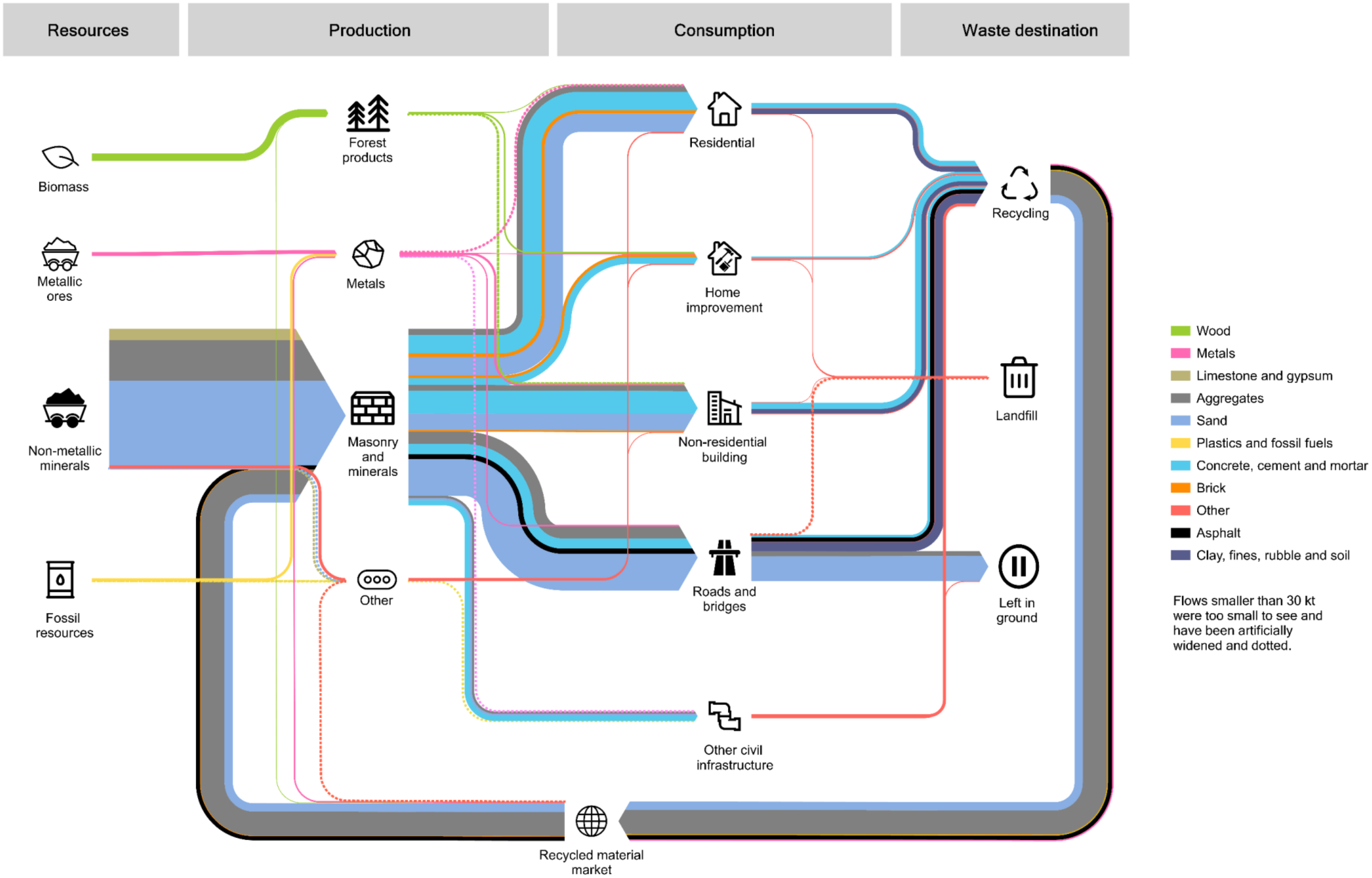


Figure 9 Material flow analysis of the built environment

## Carbon perspective

Figure 10 compares the amounts of key materials used in construction in South Australia with the embodied greenhouse gas emissions associated with their production.

While aggregates and sand are two of the most consumed materials, their extraction results in relatively low greenhouse gas emissions.

Conversely, some materials are used in comparatively small amounts, but are significantly more intensive in terms of greenhouse gas emissions. This is for instance the case for steel and aluminium, where the impact on climate change per kilogram of metal is comparatively high. This shows that although the built environment consumes much fewer metals compared to minerals such as sand and aggregates, the greenhouse gas impacts of metals is an order of magnitude higher.

In the case of concrete, both the material flows and associated greenhouse gas emissions represent a significant portion of the total. Concrete is both one of the largest material flows found in the built environment, and the most impactful material. This analysis would support targeted efforts to reduce the relative impacts of producing concrete (per $m^3$ of material), as well as reducing its use altogether, where possible.

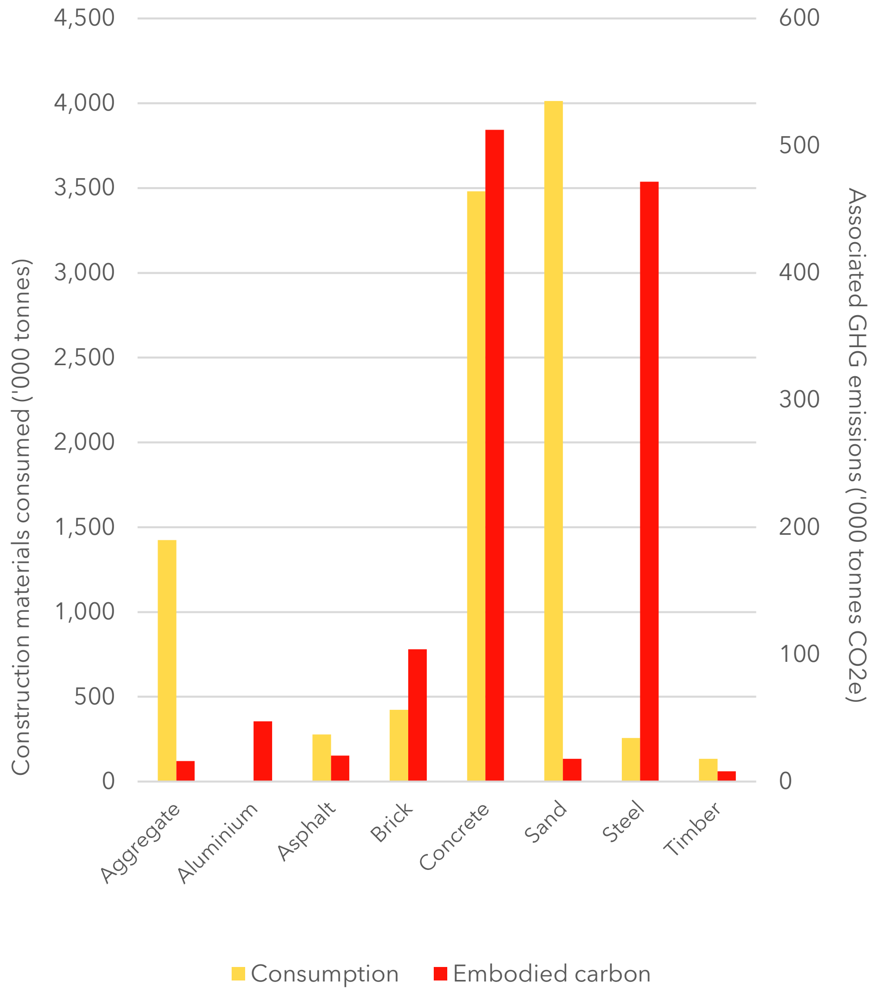


Figure 10 Comparing construction materials consumption with associated embodied carbon

The focus of this study has been on the materials used within the built environment in South Australia. However, the environmental impacts of the built environment as a whole encompass both the embodied and operational impacts of the buildings. Operational impacts are linked to heating, cooling and lighting the building during use, as well as the operation of all other systems required in buildings and infrastructure. In 2019, operational impacts accounted for 84% of the total greenhouse gas impacts associated with buildings in Australia (Figure 11 [83]). This goes to show that the materials alone do not represent the whole picture of the built environment's greenhouse gas impact. However, as improved designs, technological advances and investments reduce the operational requirements of buildings, and as the uptake of renewable electricity production improve the carbon profile of the grid, it is expected that embodied carbon emissions will represent a larger portion of the total impacts in the future.

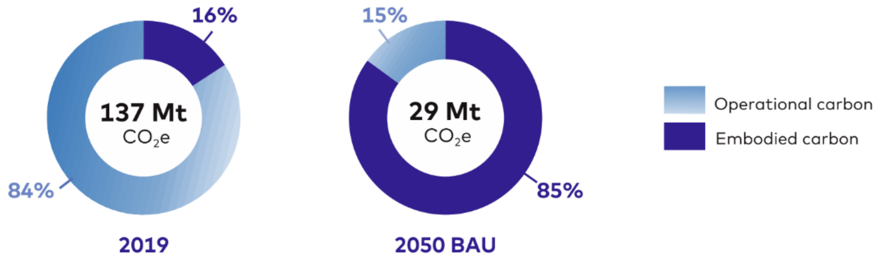


Figure 11 Operational and embodied carbon in Australian buildings

The greenhouse gas emissions of the built environment are also influenced by the choices made when buildings reach their end of life. The MFA shows that the construction and demolition waste sector has high recovery rates of materials. However, the majority of materials recovered are downcycled. Downcycling occurs when the recycled material is of lower quality and functionality than the original material. For example, when concrete is recycled, it is not utilised as concrete, but as aggregate. This means that the loop is not closed, and functionality of the material is lost.

When assessing end-of-life options, the most benefits can be obtained by maintaining the highest possible functionality of the material. For example, in the worst case, a brick recovered from the demolition of a building would be sent to landfill. Here, all value of the brick is lost, and to construct a new building, materials for a new brick would need to be extracted and processed, causing environmental impacts. Alternatively, if the brick is recycled, some value of the material is maintained. The brick could be crushed and added to concrete as aggregate, reducing impacts by avoiding the need to extract virgin materials for use as aggregates. However, recycling still utilises energy. Therefore, the most preferable pathway would be to maintain maximum value of the brick by reusing the product for its original function. If the brick is reused in construction of a new building, no virgin materials need to be extracted and no further processing performed, resulting in the largest savings in greenhouse gas emissions overall.

While reuse may not currently be practical for all materials, this mindset of prioritising reuse and remanufacture over recycling is critical for reducing end-of-life impacts of construction materials. Ultimately, building design should allow for ease of disassembly of parts, enabling maximum possibility for reuse of components and hence maintaining value and reducing environmental burdens.

**CASE STUDY – BRICK CLEANING IN DENMARK**
http://en.gamlemursten.dk/

In Denmark, Gamle Mursten cleans old bricks for reuse having developed a mechanised process to efficiently remove mortar and concrete from bricks sourced from demolition sites. The potential for brick reuse in Denmark is estimated at 10% of total brick production [84].
Reused bricks are used in building façades as architectural features. While the labour intensive process to dismantle and clean bricks has a cost implication, the reuse of bricks can save about 500 g $CO_2e$ per brick reused [85].

## Circularity score

This baseline assessment indicates that the built environment sector in South Australia is 22% circular according to the NCM, with an MCI of 0.5, as outlined in Table 9.

In the built environment the different approaches between the NCM and MCI become apparent, with South Australia's high recycling performance in the built environment reflected in the stronger MCI score.

The greatest opportunity for improvement lies in the reuse of building materials, with only 1% of materials currently being circulated through reuse. Reuse of building materials relies on systemic changes from many directions, but can be greatly improved through the implementation of design for durability/longevity, and design for disassembly. Improvements in these areas are imperative for enabling reuse of building materials at end-of-life.

Table 9 Circularity metrics for the built environment

| Category | | Score |
|---|---|---|
| **Circular inputs (feedstock)** | Feedstock reused content | <1% |
| | Feedstock recycled content | 21% |
| | Recycling efficiency | 72% |
| | **Circular inputs** | **22%** |
| **Circular outputs (end of life)** | EOL to reuse | 1% |
| | EOL to recycling | 88% |
| | Recycling efficiency | 72% |
| | **Circular outputs** | **89%** |
| **MCI** | | **0.5** |
| **NCM** | | **22%** |

# Textiles

Globally, consumers purchased 60% more items of clothing in 2014 than 2000, and kept them for half as long [86]. In Australia, textiles are the least recycled waste stream, and the manufacture of textiles has significant impacts on the environment including water consumption, the intensive use of chemicals, and greenhouse gas emissions associated with the supply chain.

But the textile sector is much broader than clothes, including products like car seats, mattresses and geotextile membranes. These products are made from a wide range of materials, have different lifespans and are used across all sectors of the economy.

## Sector categorisation and key data sources

The model characterises textiles flows into 12 products over 6 product categories (Table 10) and 24 materials over 4 material categories (Table 11). The product categorisation was developed by amalgamating existing waste classifications in Australia and the material categorisation developed based on categories that would accurately describe the material flow. While identified in the data categorisation, chemicals, metal, and wood are excluded from the final material flows as they are not themselves textiles.

Table 10 Textiles categorisation

| Product category | Product | Example |
|---|---|---|
| **Clothing and footwear** | Apparel | T-shirt |
| | Footwear | Leather shoes |
| **Carpet and flooring** | Carpet and flooring | Rugs, carpet by the roll, carpet squares |
| **Fibre, fabric, and yarn** | Fabric | A sheet of leather |
| | Fibre | Raw wool |
| | Yarn | Cotton thread |
| **Furniture, mattresses, and home textiles** | Furniture | Couch |
| | Home textiles | Curtains |
| | Mattresses, quilts, cushions, and pillows | Mattress |
| **Industrial textiles** | Industrial textiles | Conveyor belts, fishing nets |

## Modelling approach and assumptions

This model uses a stock and flow approach but assumes that inputs and outputs of textile products in the economy are at an equilibrium. As such the build-up of stocks over time was excluded.

The model uses imports and domestic production as system input nodes. Raw resource inputs are backwards calculated as inputs to these nodes, namely biomass and fossil resources.

Product exports, recycling exports, and landfill are system output nodes. Flows within the system were modelled using ABS, consumer behaviour, recycling and waste data.

The model was used to analyse the material composition of each product flow at each life cycle stage. For example, at the product mix stage, the mass of clothing flow was calculated, including the mass of each of the 24 materials in that flow. The same was calculated for each of the other 12 products.

Data was collected to determine the total flow of textile products, which were then further disaggregated into individual products and materials based on secondary sources of data. In turn, these were allocated to the product users in the various parts of the economy.

The modelling of the textile sector was particularly ambitious given the low availability of specific data and existing models in the Australian setting. The model draws upon the following diverse data sources and assumptions:

- Raw material equivalent flows were modelled using factors derived from AusLCI [30].
- Import and export data were sourced from international trade data, specifically ABS Input-Output data [87]. Domestic production data was sourced from the ABS [87] and from ABARES [88]. Material composition data, where the above sources did not give sufficient detail, was augmented by Comtrade trade data accessed through the World Bank's World Integrated Trade Solution (WITS) [89] and by studies on specific textile flows [90].
- Data for reuse through informal transactions (such as giving items to family) and reuse through charitable giving was sourced from studies on textile disposal methods and from data reported by charities [63], [91], [92]
- Recycling data was provided by South Australia's Recycling Activity Survey [7] which includes a final value of recycled material for textiles (excluding rubber). Input flows were estimated by applying factors to textile and rubber recycling values in the Recycling Activity Survey.
- Initially, landfill data was provided through the National Waste Report and several studies on detailed waste compositions. The quality of the landfill data proved to be unreliable, so it was not used directly. For example, categorisation from one source included tyres in the rubber category yet another source did not, leading to significant differences. Instead, a simple input-out balance was adopted using the existing, more reliable data. To determine the landfill flow, reuse and recycling flows were subtracted from the textile input flow.
- While included in the ABS data, 'domestic textile finishing' and 'textile repair' were excluded due to lack of data on flow characteristics, and their flow represented less than 0.5% of the total flow.

Table 11 Material categories for textile material flow

| Material category | Materials | |
|---|---|---|
| **Wool** | animal hair | wool |
| | animal skins | |
| **Cotton** | cotton | - |
| **Non-synthetics** | animal furs | human hair |
| | coconut and other vegetable fibres not elsewhere classified | jute and other bast fibres (excluding flax, hemp and ramie) |
| | flax | leather |
| | hemp | silk |
| **Synthetics** | acrylic | polyurethane (PU) |
| | nylon | polyvinyl chloride (PVC) |
| | polyester | rubber |
| | polyethylene terephthalate (PET) | viscose |
| | polypropylene (PP) | |

## Material flow results

The material flow assessment of textiles in South Australia is provided in Figure 12.

The textile material flow in South Australia is dominated by imported products, with most domestic production destined for export (largely wool and animal skins/leather from sheep and cows).

The domestic production of wool dominates the MFA. Wool is predominantly exported as a primary product and dwarfs the local textile manufacturing industry, with secondary sector exports being multiples lower. 45,400 tonnes of wool production are exported, 59% of the 76,600 tonnes of total primary exports. It follows that wool also dominates raw resource consumption. The effect of the sheer mass of wool produced locally is exacerbated by the fact that wool consumes around 7 times as much raw resources as synthetics[4].

The total amount of textiles consumed annually in South Australia is estimated at 220,306 tonnes, or 124 kg per capita. If considering imports only, this equates to 86 kg per person. To compare, a report from the Australasian Circular Textile Association (ACTA) [93] estimated textile flows based on imports as 39 kg per capita. The difference between these per-capita values lies in methodological approaches. While both models use ABS data, the ACTA report uses trade data and the model presented here uses ABS Input-Output data. The conversions to mass flows will therefore differ. Further, there are significant aggregation differences between the ABS trade data and the ABS Input-Output data. This means that the products included or excluded in each data source may differ significantly.

The items that are both produced and consumed in Australia tend to be bulkier items, such as flooring, that are more practical to produce locally. Clothing and textiles are the smallest flow of the products produced and consumed locally.

Donations to charities are an important player in the reuse of clothing and footwear textiles and to a lesser extent home textiles and furniture. Industrial textiles are understandably not recycled through op shops, although some flooring, in the form of rugs, may pass through them. 15,480 tonnes of textile donations are directly reused.

The informal selling or giving away of textile products is a surprisingly significant flow at 29,580 tonnes. The data used to calculate these informal reuse flows, however, is self-reported survey data [92], which may overestimate this flow due to the difference in consumers' reported behaviour and actual behaviour.

Recycling is a minor flow overall, estimated at 4,380 tonnes, only 2% of all textiles consumed in South Australia. The landfill flow of 170,500 tonnes (77% of textile consumption) dwarfs the recycling flow, with the remaining 21% going to reuse.

**CASE STUDY – OP SHOPS**

The Charitable Reuse and Recycling Sector is significant in Australia, with over 2,600 shops distributed across the country. A 2021 study found that over 1 million tonnes of donated products were managed by the sector, about 30% of which is clothing [63]. Of this stream, only 14% was reported to be lost to landfill. In this system, charitable institutions act as central points of high-value resource recovery in Australia, sorting between products which can be on-sold, directing specific streams to recycling processes, export, or as a last resort, landfill.

[4] According to data derived from the AusLCI database, around 15 kg of raw biogenic resources are consumed for 1kg wool, and around 2 kg of raw fossil resources for 1 kg of synthetic fibres.

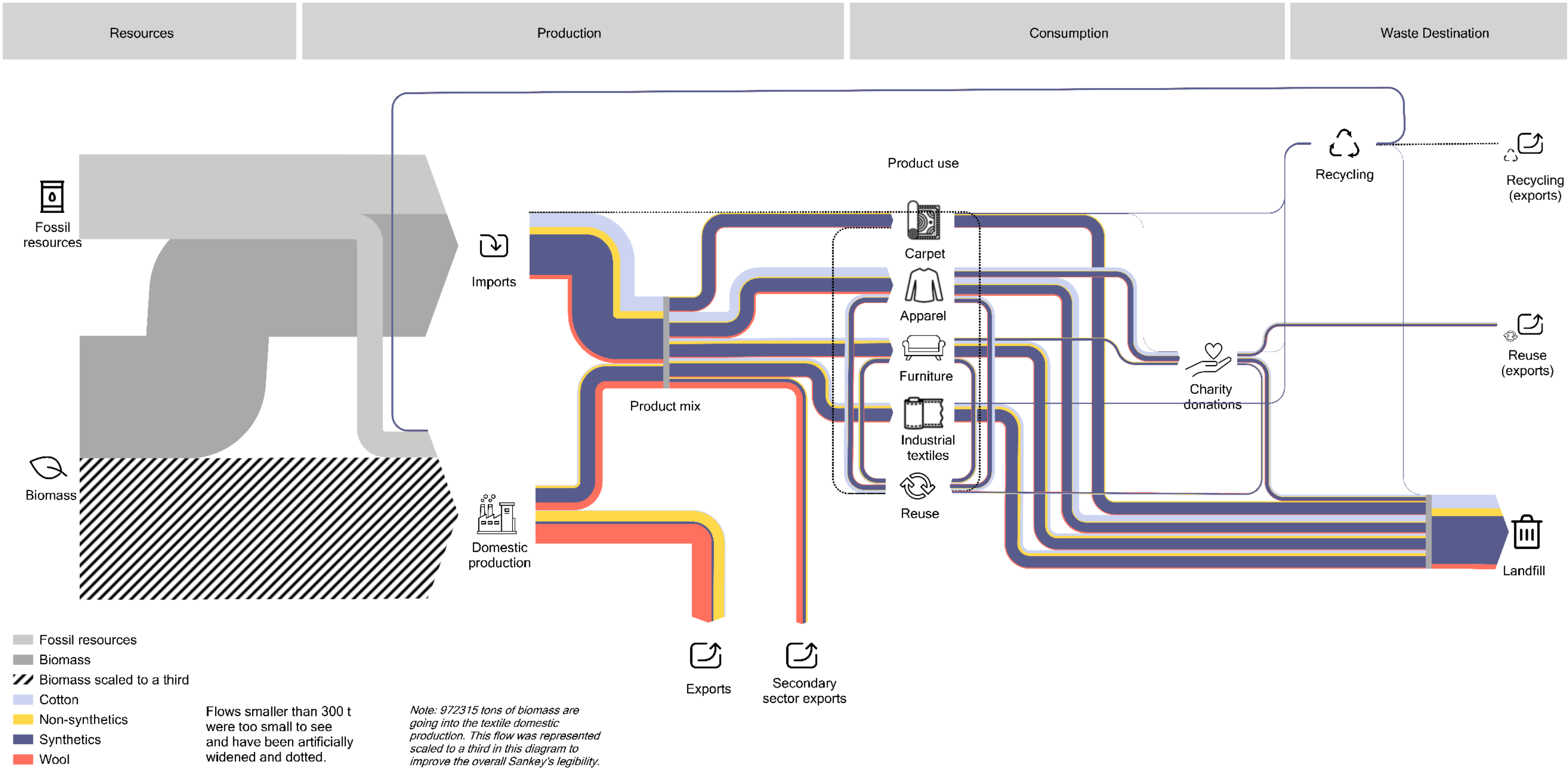


Figure 12 Material flow analysis of textiles

## Carbon perspective

Figure 13 compares the amounts of key materials used in textile products in South Australia with the embodied greenhouse gas emissions associated with their production.

Wool has relatively high embodied carbon, with 14,100 tonnes of material generating 764, 600 tonnes $CO_2e$. In comparison, 21,500 tonnes of non-synthetics (excluding cotton and wool) generate 116,400 tonnes $CO_2e$. This type of comparison highlights the need to dig into specifics when comparing this macro level data – the materials are often used in different product applications, so such a comparison does not always reveal the full story. For example, coconut fibre would likely be used in a less processed, less energy intensive form, such as woven string, rather than the more energy intensive finely knitted form that wool is often used in.

The use phase can have a significant impact on the overall embodied carbon of a product. Although the model presented here does not account for product use, it is important to understand how this may affect life cycle greenhouse gas emissions. For clothing textiles, the use phase ranges from 93% to 2% of life cycle $CO_2e$ emissions [94]. Clothing textiles can have very different use phases, from wool suits that are rarely, if ever, washed, to sportswear that is washed after every use. The use phase of denim jeans generates 57% of its life cycle $CO_2e$ emissions, with an average of 104 washes in its life [94].

Different textiles also behave differently across various end-of-life destinations. For example, in landfill, organic textiles such as cotton and textiles will degrade, releasing greenhouse gases, while synthetic materials such as polyester and acrylic remain inert for extended periods of time. Both organic and synthetic materials can be recycled back into fibres, but there can be a loss in quality along the way [95].

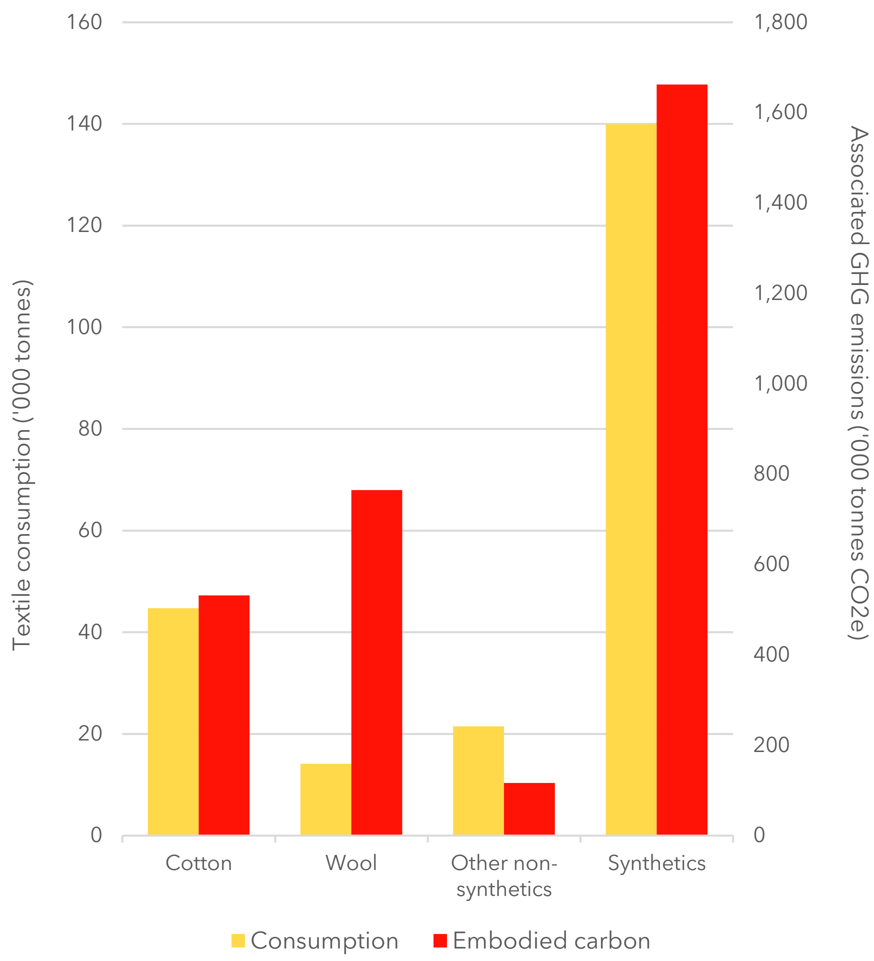


Figure 13 Comparing textile consumption with associated embodied carbon

## Circularity score

This baseline assessment indicates that the textiles sector in South Australia is 4% circular according to the NCM, with an MCI of 0.20, as outlined in Table 12.

Textile reuse represents the percentage of textiles reused or donated. While textiles collected at end-of-life are often applied to lower value uses, i.e. used as rags, recycling of textile fibres is still in its infancy in Australia [95]. This low recycling rate affects the overall MCI and NCM scores.

Table 12 Circularity metrics for textiles

| Category | | Score |
|---|---|---|
| **Circular inputs (feedstock)** | Feedstock reused content | 1% |
| | Feedstock recycled content | 3% |
| | Recycling efficiency | 75% |
| | **Circular inputs** | **4%** |
| **Circular outputs (end of life)** | EOL to reuse | 16% |
| | EOL to recycling | 2% |
| | Recycling efficiency | 78% |
| | **Circular outputs** | **18%** |
| **MCI** | | **0.2** |
| **NCM** | | **4%** |

# Next steps

This report contains the most comprehensive accumulation and visualisation of material flow data for any state or federal government in Australia. It provides insights into the successes, failures, and challenges in developing a circular economy at scale. This new information offers an evidence base to drive conversations, actions and strategies that support the transition from a linear to a circular economy.

Short term actions can plug gaps in existing recovery processes while longer term strategic actions need to address issues in problematic sectors where reuse and recycling are the exception rather than the norm. At the sector level it is important to integrate the mass information with other objectives of climate policy, economic development objectives and social inclusion.

While the models developed for this project are best practice, modelling complex economic and physical systems at multiple scales is challenging to say the least. This study has been named Version 1.0 to reflect the importance to improve this first 'line in the sand'.

Completing the analysis relied on combining information from a broad range of resources, from past life cycle assessment models to state and federal reports, scientific literature and more. In addition, several aspects had to be modelled using key working assumptions. The results provide a good sense of the scale of the material flowing through the economy, as well as a translation in carbon implications associated with these material and products streams.

One temptation would be to recommend impracticable level of data collection for further updates. Of course, data availability is key to successfully modelling an MFA. However, it is difficult to imagine a data collection system at the state level for all key economic sectors, to the level of detail achieved here.

As such, focussing data collection on the following key areas with high uncertainty is recommended:

- reuse, repair and second-hand markets
- end-of-life
- use phase
- domestic production.

Regarding future updates of South Australia's material flows, the effort required varies for each of the models, depending on their level of complexity and the extent to which standardised data sources are available. Recurrent updates would enable tracking of South Australia's real progress to becoming a circular economy, and could be coupled with key performance indicators to track activities, outputs and outcomes that support the transition.

This work would require the development of a detailed update regime, based on the properties of both the data sources and the different models.Each model should be considered as standalone product, with a different update regime. For instance, the electronics model relies heavily on international trade data, and a large part of it can be updated relatively easily, while other data sources such as the material breakdown of electronic products may remain static over time.

**Reuse, repair and second-hand markets**

Calculating the amount of products being reused instead of discarded relies upon high-level estimates and could benefit from further research. The reuse sector is often informal, and could include person-to-person transactions, charity donations and resell as well as larger schemes. It is a difficult sector to collect data for as it includes a multitude of small actors. In addition, the boundary between what constitutes genuine reuse that avoids waste production and the typical use of stock is not clear.

The authors recommend conducting an analysis focusing on the stock of products and defining how they move through the economy. For instance, being able to differentiate between the volume of products being repaired and the volume sold on the second-hand market through established channels could be useful in designing more targeted policies and tracking their success over time.

**End-of-life**

Overall waste management is well documented in South Australia. However undertaking additional data collection at a more granular level for certain products would provide additional clarity in the analysis.

In the e-waste stream, volumes collected through product stewardship schemes and going to high efficiency recycling systems are very well documented. However, the bulk of the waste collected for recycling is likely to go to low-efficiency recycling. This is poorly documented as it is generally informal and could benefit from additional information. For instance, knowing with certainty the volume of e-waste going to scrapyards for metal recovery would be useful. In addition, although there is a landfill ban on e-waste, there are no specific schemes tasked with managing this waste and therefore no data could be identified on the effect of the landfill ban on the waste management system. This is an area that could benefit from further exploration.

In some cases, the volume of waste going to recycling systems was well documented, like in the construction and demolition sector, but the end-use of this material was not. Green Industries SA would benefit from knowing in more detail how these recovered resources are used and what raw commodities they displace, to understand the benefit of recycling.

**Use phase**

For the most part, the use phase is irrelevant to the MFA, apart from the construction sector for which it was included as home improvement.

However, as mentioned throughout the report, it is a key element when considering carbon emissions, as it often is more significant than the manufacturing of the product itself. Understanding the effect of the use phase in more detail could be beneficial in developing policy which targets the right part of the supply chain. For instance, understanding the trade-off between reducing carbon emissions from the operational phase of a building and potentially the additional embodied carbon emissions associated with making those buildings more efficient.

**Domestic production**

The volume of products coming out of manufacturing in South Australia is not well documented. In some case, it was simply excluded from the analysis. As such, putting systems in place to document what and how much is being manufactured in the state would be a useful piece of information for future updates of this work.

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