Potential environmental benefits of e-waste recycling in Australia

FY24

Undertaken by Lifecycles for the Australian and New Zealand Recycling Platform (ANZRP)

Citation	Bontinck, P.-A. (2024), Potential environmental benefits of e-waste recycling in Australia – FY24, Lifecycles, Melbourne, Australia.
Copyright	
Important disclaimer	Lifecycles advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, Lifecycles (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Contents

Figures

Tables

1 Introduction

1.1 Context

Australia and New Zealand Recycling Platform (ANZRP) is a not-for-profit Co-regulatory Arrangement operating under the National Television and Computer Recycling Scheme (NTCRS).

ANZRP manages the national e-waste recycling service TechCollect, covering computers, computer accessories, printers and televisions from households and businesses.

To demonstrate its commitment to best-practice environmental outcomes, fact-based analysis and transparency, ANZRP has engaged Lifecycles to calculate the environmental benefits of its operations for its annual report since FY2016.

This report presents the updated environmental data for FY2024, covering the benefits of e-waste recycling on climate change, water and energy use and particulate emissions.

1.2 Life Cycle Assessment

LCA is a methodology for assessing the full ‘cradle to grave’ environmental benefits of products and processes by assessing environmental flows (i.e. impacts) at each stage of the life cycle. LCA aims to include all important environmental impacts for the product system being studied. In doing so, LCA seeks to avoid shifting impacts from one life cycle stage to another or from one environmental impact to another.

The framework and principles of LCA are described in the international standard ISO 14040 [1]. The general structure of the LCA framework is shown in Figure 1. Each stage of the LCA interacts with the other stages which makes LCA an inherently iterative process. The specific requirements for LCA are defined by ISO 14044 [2].

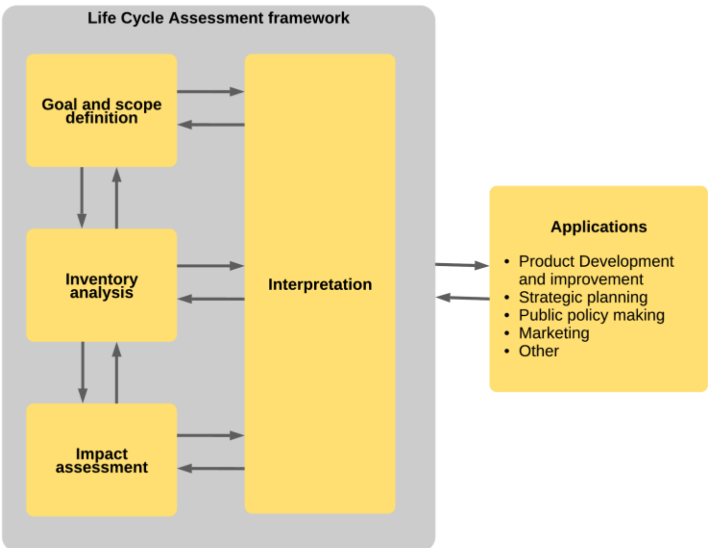

Figure 1 Framework for life cycle assessment.

- The first stage (**goal and scope**) describes the reasons for the LCA, scenarios, boundaries, indicators and other methodological approaches used
- The second stage (**inventory analysis**) builds a model of the production systems involved in each scenario and describes how each stage of the production process interacts with the environment
- The third stage (**impact assessment**) assesses the inventory data against key indicators to produce an environmental profile of each scenario
- The final stage (**interpretation**) analyses the results and undertakes systematic checks of the assumptions and data to ensure robust results

2 Goal and scope

2.1 Reason for the study

This analysis aims to answer two questions, as described below.

1. **What are the environmental impacts associated with the collection and recycling of e-waste collected through ANZRP’s TechCollect program?**
   The recycling of e-waste into secondary materials relies on a complex system of processes used to separate and refine individual material fractions. These can range from simple processes (e.g. magnetic separation) to sophisticated processes requiring significant energy inputs (e.g. pyrometallurgy).
2. **What environmental benefits can be derived from the recovery of secondary materials in this system?**
   E-products are manufactured using a broad range of materials, many of which can be recovered as secondary materials. The model is built under the assumption that the production of secondary materials will displace the use of an equivalent amount of virgin materials. This analysis aims to quantify the mass of recovered material, the primary material it displaces, and the environmental benefits associated with avoiding the production of those primary materials.

2.2 Intended audience

ANZRP is planning to use information resulting from the analysis within ANZRP’s annual report and in public communications.

2.3 Functional unit

The functional unit (FU) is the basis for the comparison of alternatives in LCA. It describes the service delivered by the processes being studied. The primary intention of the study is to analyse the environmental effects associated with the e-waste recycling program operated by ANZRP. Thus, the functional unit has been defined as:

“the collection and recycling of 1 tonne of mixed television and computer waste, collected from Australia, as defined within the scope of the NTCRS, during financial year 2024”.

2.4 System boundaries

The system boundary diagram reported in Figure 2 illustrates the boundary considered for the study, which includes the collection and recycling of e-waste managed by ANZRP.

A description of the steps considered within the system boundary is reported in Section 2.4.1, while excluded processes are identified in Section 2.4.3. As outlined by the functional unit and information provided in this section, the scope of this analysis is cradle to gate. Because their inclusion would not support answering the research question, the manufacture and use of the products, as well as their transport to the drop-off site, were not considered in this analysis.

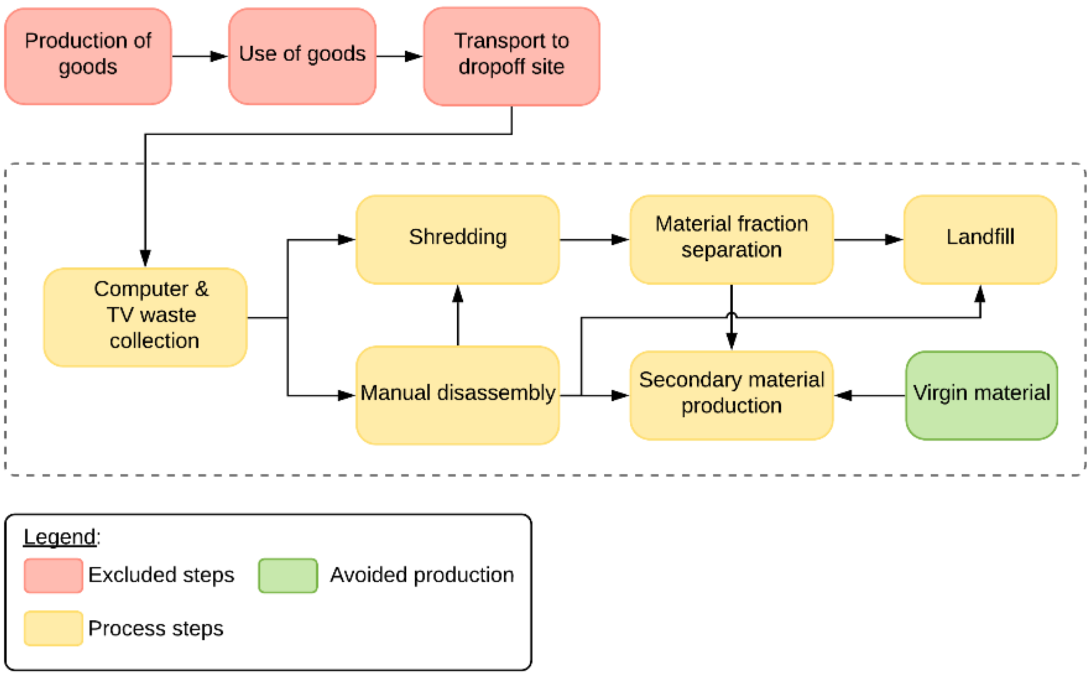

Figure 2 System boundaries considered in this analysis.

2.4.1 Included processes

The analysis covers all relevant steps of the e-waste collection and recycling system:

- *Transport of e-waste* from the point of collection (or drop-off site) to each recycler involved in the program
- *Initial processing of e-waste* at each recycler's facility, including in the first instance a mix of manual disassembly and mechanical processing, followed by a series of material fraction separation processes (e.g., magnetic separator, eddy current, etc.).
- *Transport of separated fractions* to downstream processor, domestically and overseas
- Further dismantlement of specific component and *specialist recycling processes* (e.g., hydrometallurgy, pyrometallurgy, etc.).

The boundaries of the system end at the point where a secondary material ready to be used as an input to new products has been obtained. An example might be a clean stream of aluminium separated using an eddy current process, sold to a furnace.

2.4.2 Cut-off criteria

Any excluded flows must fall below the cut-off threshold for this study (below 1% of total greenhouse gas emissions). The system boundary reported in Figure 2 is simplified. Though not all steps and processes used in the management of e-waste are shown, these are included in the analysis. The model built for this analysis relies on ecoinvent v3.10 and AusLCI v2.44. These systems are built with no cut-off, meaning that all flows are considered, including capital formation.

2.4.3 Excluded processes

Within the cradle to gate boundary of the system, the analysis excludes several flows, as defined below:

- Transportation of employees to and from the site, as well as any catering on-site.
- Manual disassembly of incoming waste.
- Non-material services associated with recycling operations (e.g. insurance, finance, etc.).

2.5 Flows included in the life cycle assessment

A life cycle assessment aims at measuring the exchange between the natural world (the '*biosphere*') and human activities (the '*technosphere*'), either via the extraction of natural resources or the emissions of pollutants to air, water and soil. The measurement is done at the level of the system analysed, which is broken down into a series of unit processes leading to the delivery of the functional unit, as defined in the goal and scope. A single unit process is illustrated in Figure 3. It includes flows to and from the '*biosphere'* as well as flows to and from the '*technosphere'*.

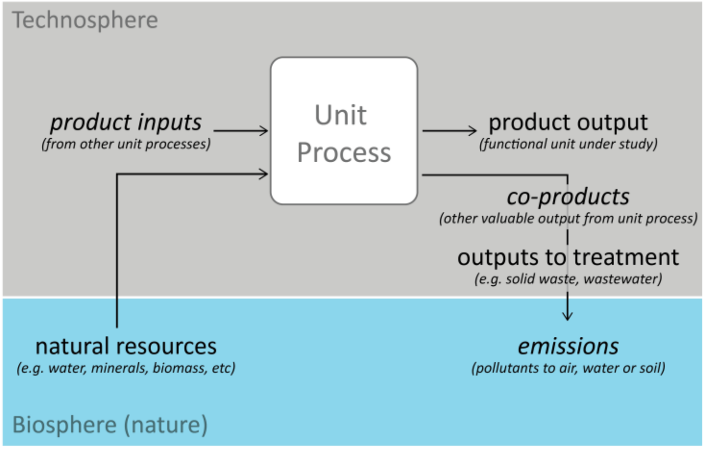

Figure 3 Inputs and outputs of a unit process in CFP.

2.6 Allocation procedures

Multifunctionality occurs when a single process, or group of processes, produces more than one usable output, or 'co-product'. ISO 14044 [3] defines a co-product as *'any of two or more products coming from the same unit process or product system'*. A product is any good or service, with value for the user. This is distinct from a '*waste'*, which ISO defines as *'substances or objects which the holder intends or is required to dispose of'*, and therefore has no value to the user.

As LCA identifies the impacts associated with a discrete product or system, it is necessary to separate the impact of co-products arising from multifunction processes.

The ISO 14044 standard provides a four-step hierarchy for solving the issue of multifunctionality (adapted from text in [4]):

1. **Avoid allocation by subdividing systems** – wherever possible, allocation should be avoided by dividing the unit process into sub-processes.
2. **Avoid allocation by system expansion** – expanding the product system to include the additional functions related to the co-products.

3. **Allocation by underlying physical relationships** – the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them.
4. **Allocation between co-products** – the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, data may be allocated between co-products in proportion to the economic value of the products.

In this analysis, recovered secondary materials are assumed to have the same inherent properties as virgin equivalents. Thus, the model is built to represent the assumption that the creation of recyclable material results in the displacement of virgin materials and the emissions and removals associated with its creation.

2.7 Characterisation model

In LCA, the impact assessment stage relates the inventory flows to the indicators selected. This is done by classifying which flows relate to this impact category and selecting a characterisation model that quantifies the relationship of each inventory type to the indicator in question. The calculation of the category indicator results is the sum of all inventory flows multiplied by their relevant characterisation factors.

The indicators chosen for this analysis are expected to be the most relevant to recycling industries, at the exception of human and ecotoxicity indicators which are not included due to large uncertainties in the models and background data used in the study. A summary of the impact category selected for the study can be found in Table 1.

Table 1 Impact categories and characterisation models of the study.

Indicator	Description	Characterisation model
Climate change	Radiative forcing as Global Warming Potential (GWP100) Expressed in kg CO_2 eq. This is governed by the increased concentrations of gases in the atmosphere that trap heat and lead to higher global temperatures. Gases are principally carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).	(IPCC 2021) IPCC model based on 100-year timeframe + some factors adapted from EF guidance.
Resource use (energy carriers)	Abiotic resource depletion – fossil fuels. Expressed in MJ lower heating value. Depletion model based on use-to-availability ratio. Full substitution among fossil energy carriers is assumed. It includes all energy resources extracted and used in any way. It does not include renewable energy, energy from waste or nuclear energy.	(Guinée et al., 2002) CML 2002 and van Oers et al. 2002.
Particulate matter	Measured in g PM2.5. This impact category looks at the health impacts from particulate matter for PM10 and PM2.5. This is one of the most dominant immediate risks to human health as identified in the global burden of disease.	(Humbert et al. 2011) World impact plus method.
Water scarcity	User deprivation potential. Expressed in m^3 world eq. Represents the relative Available WAter REmaining (AWARE) per area in a watershed, after the demand of humans and aquatic ecosystems has been met. The calculations are based on deprivation-weighted water consumption numbers.	(AWARE) Available WAter REmaining as recommended by UNEP, 2016

2.8 Limitations

This study, like any Life Cycle Assessment, has limitations. It is worth pointing out that a Life Cycle Assessment is a model, and as such it relies on assumptions and approximations. The ability to use these assumptions and approximations is what allows us to complete a Life Cycle Assessment. We rely on their robustness to provide the closest representation possible of the system under study.

In the recycling program operated by ANZRP, the primary recyclers generally conduct an initial disassembly and preprocessing step. Specific components are then directed to specialised companies which operate recycling processes designed to recover as much of the mass (including valuable content) as possible. This includes, for example, hydrometallurgical processes used for battery recycling. These companies operate one or several steps downstream from the primary recyclers, which makes it difficult to collect primary data on these processes. As a result, we resort to building models based either on information reported in the scientific literature, or using pre-existing models published in life cycle inventory databases. There are inherent uncertainties associated with this approach, which is a limitation to the study. However, we always strive to review the available literature to identify the most representative data available. This means that our models for downstream recycling processes are always built from the best available data, and as such are an appropriate representation of these processes.

On the other hand, the breakdown of materials recovered is well understood and represented, relying on highly detailed material breakdown reported by recyclers. This is particularly the case for base metals (iron, aluminium and copper), the recovery of which typically provides the majority of environmental benefits. As such, we are confident that the overall outcome of the study is a good representation of the system operated by ANZRP.

3 Inventory

Inventory analysis is the stage of the LCA in which the system being studied is broken up into unit processes, which are modelled by quantifying relevant inputs and outputs. These unit processes are linked to create a system that produces the functional unit of the study, as illustrated in Figure 4. They can be categorised into foreground unit processes and background unit processes:

- **Foreground processes** are those for which specific data are collected for the study. This includes primary data collected from facilities, secondary data from published papers and modified background processes from LCA databases.
- **Background processes** are those for which data are typically sourced from pre-existing databases. The background data are either less important to the study outcomes or are already well-characterised in the existing data sets and therefore do not warrant specific modelling. Background processes are used to connect the model during an analysis with their complete supply chain, so that a full cradle to grave assessment can be conducted. Here, AusLCI v 2.44 [5] is used as the database of reference for processes taking place in Australia (e.g. maintenance events), while ecoinvent v3.10 [6] is used as the database of reference when inputs are deemed to be sourced from the global supply chain. Both libraries use economic allocation throughout.

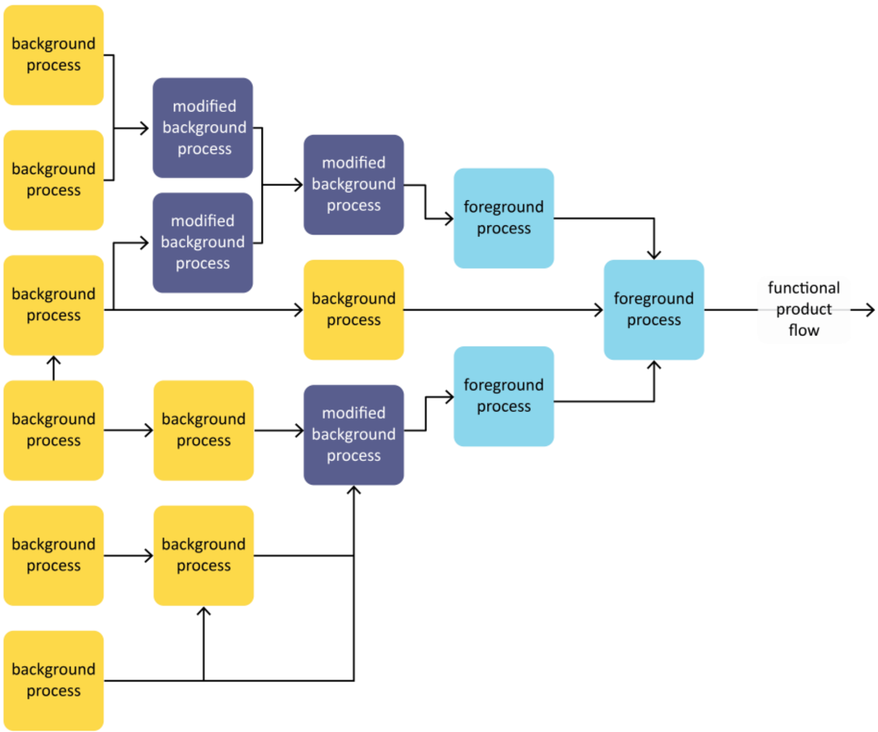

Figure 4 Linking unit processes in a carbon footprint to produce the functional unit.

The following sections outline the sources of the background and foreground inventory data.

3.1 Foreground data

3.1.1 Inbound e-waste logistics

Freight efforts are modelled using a tonne.km unit, which represent the requirements of moving one tonne of goods over one kilometre.

To represent the freight efforts associated with bringing e-waste from its collection point to each recycler, a detailed matrix of logistics was obtained from ANZRP. This dataset provides information on the mass of waste collected from each collection point, as well as the recycler to which it is transported, and the distance travelled.

Overall, road freight remains by far the principal mode of transportation used to carry e-waste from its original collection point to each recycler, representing over 90% of the total freight effort.

Table 2 Inventory table – total freight effort required to transport e-waste.

	Mass collected *tonnes*		**Road freight**	**Sea freight**	**Barge freight**	**Rail freight**
	TV	**IT**	*t.km*	*t.km*	*t.km*	*t.km*
ACE Recycling Group	1,761	8,213	1,793,532	77,520	1,158	43,540
Electronic Recycling Australia	674	773	120,079	0	0	0
Endeavour Foundation	601	442	126,886	570	7,311	0
Sircel Victoria	945	1,281	178,622	31,616	0	0
TES-Amm	0	584	13,435	0	0	0
Total Green Recycling	1,259	1,270	264,418	1,736	0	0
TOTAL	**5,240**	**12,563**	**2,496,973**	**111,441**	**8,469**	**43,540**

3.1.2 Preprocessing at initial recycler

Upon delivery to each of the recyclers contracted by ANZRP, the e-waste will undergo an initial preprocessing step. Two processes can typically take place:

1. *Manual disassembly*: the e-waste is disassembled to separate clean fractions (e.g. ferrous metals, non-ferrous, plastics, etc.), or specific components (e.g. batteries, printed circuit boards, toner cartridges, hard-drives, etc.). This is done by hand, using manual or simple power tools. The environmental burdens associated with this process is assumed to be negligible and has therefore been excluded from the analysis.
2. *Mechanical preprocessing*: in some cases, the bulk of the e-waste might go through a shredding process first. In this case, material fraction separation is conducted afterwards, using specialised machinery. While televisions, desktop computers and laptops are typically disassembled, printers are often shredded. Using conservative assumptions, this analysis estimates that 23% of the e-waste collected will go through an initial shredding process.

The mechanical preprocessing step was modelled using data from the ecoinvent background database [7], modified to use electricity from the Australian grid.

3.1.3 Exported material fraction.

All the waste collected goes through an initial separation step in Australia. Once this is completed, the resulting material fractions are distributed either to downstream recyclers or is sold as a secondary material. Specific components or mixed fractions are sent to specialised recyclers, who can be operating in Australia or abroad. The information reported by each recycler allows to establish the final destination of each material fraction.

Based on the information collected, it was estimated that 89% of the e-waste collected via ANZRP is fully recycled in Australia, up to the production of secondary commodities. Once these secondary materials are obtained, they are generally sold on the global market. The buyer may be located in Australia or overseas. This step of delivery to the user of secondary material is excluded from the analysis.

Of all destinations considered, Japan represents by far the largest share of export, with 68% of the total exported flow. Approximately 81% of the waste exported to Japan is PCBs, representing 82% of all PCBs recycled through TechCollect. A major contributor to this export flow is Ace Recycling, who manages just over half of the e-waste collected through ANZRP and reported a volume of printed circuit boards (PCBs) being exported to Japan representing over 50% of the total mass of material exported to Japan.

There is a growing range of options available for PCB treatment, with recyclers reporting exporting to the Philippines, India, Malaysia and Singapore. However, Japan still processes over 80% of the total mass of PCBs recovered. Australia is a growing option, with now 13% of PCBs being processed domestically.

With the waste export ban in place, the vast majority of plastic waste is managed in Australia. The remaining exported plastic is generally a part of exported components (e.g. batteries, hard-drives, PCBs, etc.). Our assessment suggests that approximately 60% of plastic managed in Australia is recycled as a mixed plastic stream, while landfill still occurs for 35%. The remainder is either recovered as specific polymers, or as a concrete additive through the newly established RESIN8™ process.

As in previous years, all glass recovered is managed in Australia. All lead glass is treated through the Nyrstar smelter in Port Pirie (South Australia), while clean glass is either used as an input to concrete manufacturing (89%) or recycled as glass (11%).

Components such as batteries, fluorescent tubes and toner are typically managed in Australia, while ferrous metals are segregated domestically before being sold on the global market as an input to smelters. Likewise, close to 60% of non-ferrous metals are processed in Australia and sold to the global market.

Table 3 Inventory table – exported fraction in FY23.

	Proportion	**Mass exported** *(kg)*	**Typical material export**
Japan	68%	1,330,955	PCBs (81%) and non-ferrous metals (6.0%)
Philippines	19%	373,792	Ferrous metals (27%) and non-ferrous metals (47%)
India	6%	118,992	PCBs (100%)
Singapore	3%	62,681	Non-ferrous metals (57%) and ferrous metals (17%)
Asia (unknown)	3%	53,095	Ferrous metals (76%) and non-ferrous metals (20%)
Malaysia	2%	30,539	Ferrous metals (58%), non-ferrous metals (20%)
TOTAL		**1,970,053**	

3.1.4 Material fractions in e-waste

A critical aspect of e-waste recycling is the breakdown of materials found in a tonne of waste. E-waste recycling is environmentally beneficial if it can recover valuable material fractions. When recovered, these can replace virgin materials, thus avoiding their production in the first place.

The broad range of materials in e-waste includes various metals, plastics and glass. Ferrous and non-ferrous metals such as aluminium and copper are often a focus for recovery, as they represent a high proportion of the waste, can be recovered using relatively simple processes, and have a high resale value.

More complex processes are required to recover valuable material fractions from specific components, and some businesses have developed an expertise in specific streams. For instance, companies such as Mitsubishi (in Japan) or Mint Innovation (in Australia) specialise in the recovery of non-ferrous and precious metals from PCBs. In Australia, Close the Loop specialises in the recycling of toner, which it uses for its TonerPlas product.

In this study, information provided by recyclers was used to identify the material fractions found in e-waste. Precious metal fractions in PCBs were estimated based on the literature [8]. This is a limited list of materials, as it was drawn from the material being recovered, rather than from an estimate of initial composition.

Table 4 Estimated material fraction in e-waste.

Material fraction	Mass *kg / t*	Ratio *%*
Metal	**662**	**66%**
Iron	610.9	61%
Aluminium	17.8	1.8%
Copper	32.0	3.2%
Gold	0.0	0.0016%
Other metal	1.1	0.11%
Glass	**19**	**1.9%**
Clean glass	9	0.94%
Lead glass	9	0.9%
Plastics	**214**	**21%**
ABS / PC / HIPS	2.53	0.3%
PP / LDPE / PVC	0.060	0.0%
Mixed plastics	211	21.1%
Other	**105**	**10.5%**
Batteries	2.0	0.20%
Light	0.3	0.027%
Toner	0.3	0.03%
Other	102.5	10.3%

The material breakdown reported in Table 4 is summarised in Figure 5.

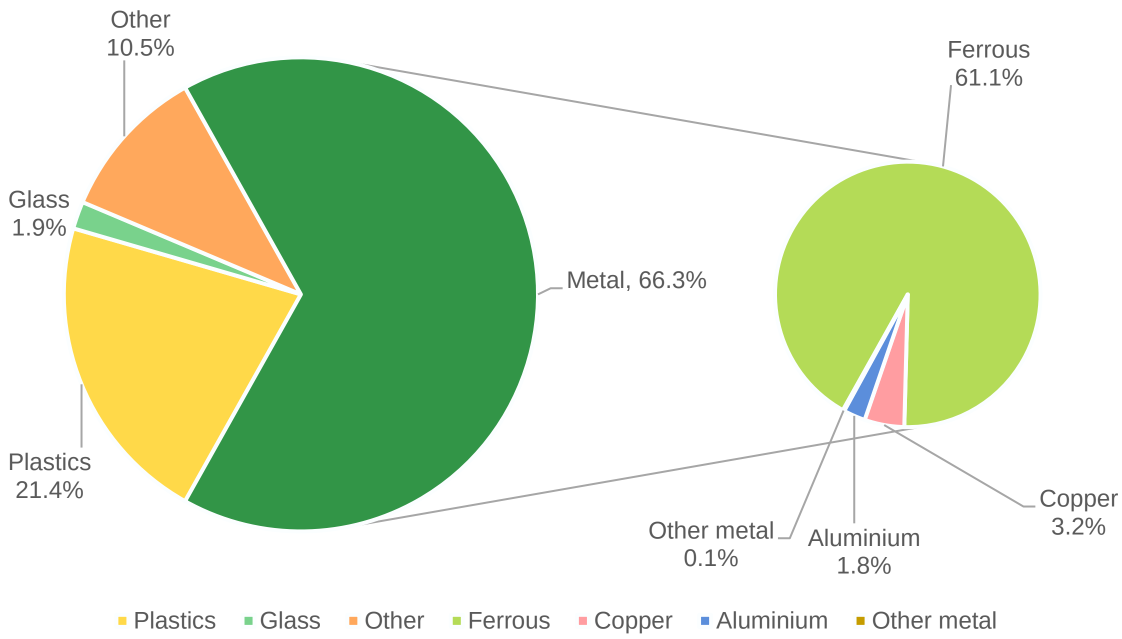

Figure 5 Estimated material fractions in e-waste collected through ANZRP.

3.1.5 Material reprocessing

Printed circuit board reprocessing

Precious metals are typically found in electronic components. As such, the reprocessing of PCBs has been the subject of much research in the past decade.

Metallurgy processes have been used extensively to recover precious metals from PCBs. Three types of metallurgical processes are typically used for metal recovery from PCBs, including:

- *pyrometallurgy* process, which allows to recover copper and gold scrap from PCBs
- *hydrometallurgy*, which recover metals through chemical leaching processes
- *bioleaching* combined with hydrometallurgy, which uses an initial hydrometallurgy process to leach copper from the waste stream, followed by the use of microorganisms to leach precious metals from PCBs

No primary data representing the exact processes taking place at the various facilities using PCBs to extract metals and precious metals could be collected for this analysis. As such, we rely on the literature to represent these processes as best as possible.

This year, each of these three processes was represented based on information published in a new publication by Schwartz et al. [9]. The study includes a detailed inventory in supplementary data, listing inputs, emissions and metal recovery rates for each process. This level of transparency allowed to recreate the inventories. The authors collated data from other publications as well as laboratory data and other publicly available information, thus it is still a step away from being a true representation of the processes as they take place in industrial facilities. However, it provides a consistent model for the different approaches used to recover metals from PCBs and is still a major improvement on the previous version of the model.

For the purpose of this analysis, the process developed by Mint Innovation could not be replicated in the model. As it is a relatively small fraction of the total PCBs being recovered, we have modelled it as going through a pyrometallurgy plant.

The model used to represent the pyrometallurgy process is based on the literature and replicates the management of PCBs through a copper smelter. The inventory developed for this analysis is reported in Table 5. We note that the table does not include the list of air emissions, for the purpose of brevity.

Table 5 Inventory for processing of PCBs through pyrometallurgy, hydrometallurgy and a combination of hydrometallurgy and bioleaching.

	Unit	Pyrometallurgy	Hydrometallurgy	Bioleaching / Hydrometallurgy
Waste input				
	kg	1000	1000	1000
Material inputs				
Activated carbon	kg	0	29	26
Calcium nitrate	kg	0	0	0.000010
Copper sulfate	kg	0	0.029	0.026
Flue gas desulfurisation	kg	0.0018	0	0.026
Hydrochloric acid	kg	0.48	153	136
Hydrogen peroxide	kg	0	40	35
Hydroxylamine	kg	0	0	0.79
Iron sulfate	kg	0	0	0.044
Kerosene	kg	0	0	27
Magnesium sulfate	kg	0	0	0.00050
Manganese dioxide	kg	0	0.051	0.045
Nitric acid	kg	0	0.11	0.098
Oxalic acid	kg	0.35	0.064	0.057
Phenol	kg	0	0	1.13
Potassium chloride	kg	0	0	0.00010
Potassium nitrate	kg	0.57	0.062	0.055
Quicklime	kg	36	119	112
Sodium borates	kg	0.54	0.059	0.052
Sodium cyanide	kg	0	1.6	1.5
Sodium hydroxide	kg	0.27	3.2	8.7
Sodium phosphate	kg	0	0	0.0005
Sulfur dioxide	kg	0	1.1	1.00
Sulfuric acid	kg	65	2.6	11
Trichloromethane	kg	0	0	2.6
Urea	kg	0.073	0.052	0.046
Water (deionised)	litre	3.6	740	757
Water	litre	22	26,134	50,648
Coke	kg	2,862	0	0
Natural gas	m^3	78	0	0
Niric acid	kg	0.28	0	0
Liquid oxygen	kg	499	0	0
Sand	kg	0	0.059	0
Energy inputs				
Electricity	kWh	88	238	870
Heat (natural gas)	MJ	0	4.1	1,135
Heat (coal coke)	MJ	13	1,260	7.9
Waste				
Wastewater	litre	1.2	24,142	21,529

	Unit	Pyrometallurgy	Hydrometallurgy	Bioleaching / Hydrometallurgy
Slag	kg	453	0.17	0.15
Hazardous waste	kg	0	693	616
Refinery sludge	kg	0	0	0.28
Material recovery				
Copper	kg	169	101	101
Gold	kg	0.139	0.141	0.141

Other recovery processes

The material recovery includes the treatments all other fractions through to the recovery of secondary materials. Our model stops at the creation of a secondary stream, which is then sold on the global commodity market. A summary of high-level modelling assumptions is provided for each fraction in Table 6.

The total fraction of waste which is exported for further treatment was estimated based on information provided by recyclers on the downstream recycling steps. Of the total volume of material collected in FY24, approximately 11% was exported for further treatment. This included principally PCBs and mixed non-ferrous metals.

The recyclers from which data was collected provided detailed information on the breakdown of materials sent for further processing, their destination and fate. This information was used to model the collection and management of e-waste in FY24.

Table 6 Summary of material recovery models used throughout the analysis.

Fraction	Location	Data source	Comments
Ferrous metal	AU	AusLCI recycling	Material offset from global supply.
Ferrous metal	IN, JP, MY, PH, Asia (unknown)	Modified AusLCI recycling	Process modified to use energy mix of the relevant country and material offset from global supply.
Aluminium	AU, Asia (unknown)	Modified internal data	Process modified to use energy mix of the relevant country and material offset from global supply
Copper	AU, IN, MY, PH, Asia (unknown)	Modified ecoinvent data	Energy for recycling from Nishtala and Solano-Mora[10] with electricity for the relevant country and offset from global copper supply.
Mixed non-ferrous	AU, JP, PH	Modified Australian LCI database	Non-ferrous metals are separated in streams – the mix of metals is estimated from data reported by CDS. Reprocessing energy from Grant et al.[11] adjusted to energy in the region and offset from global supply.
Plastics	AU	Modified Australian LCI database	Energy from Grant et al.[11] adjusted to energy in the region and offset from global supply.
Mixed plastics	AU, IN, JP, PH	Modified Australian LCI database	Energy from Grant et al.[11] adjusted to energy in the region. Used either as an input in concrete, where it is assumed to offset sand, or pelletised to produce consumer goods, where it is assumed to displace virgin polypropylene.

Fraction	Location	Data source	Comments
Toner cartridge	AU	Berglind & Eriksson [12], and ACS [13]	Adaptation of work identified in the literature to model the breakdown of material found in toner and ink cartridges, combined with work conducted by Lifecycles to model the process taking place at Close the Loop.
Battery	AU	Fisher et al. [14], and previous LCA work	Adaptation of work identified in the literature to model various battery recycling processes, differentiating between specific chemistry, combined with previous work conducted by Lifecycles.
Fluorescent tube	AU	Modified ecoinvent model and Australian LCI data	Adaptation of existing data, which vary depending on the stream considered
PCB	JP, SG, AU, IN, MY, PH, Asia (unknown)	Schwartz et al. [9], with metal content sourced from Oguchi et al. [8].	Process estimated from the available literature, with outputs aligned with typical metal content of PCBs and typical reported efficiencies.
Landfill	AU, IN, MY, PH, Asia (unknown)	AusLCI landfill process	Unmodified background model.
Glass	AU	Average recycling	All glass recycling is assumed to be to non-glass uses, namely aggregate.
Lead glass	AU	Ecoinvent lead smelting process	Modified ecoinvent model using data from Nyrstar. Based on the literature, lead glass is often directly sent to a lead smelter, where lead is separated from the glass.

4 Results and interpretation

4.1 Evolution of results over time

Lifecycles has been conducting this analysis since financial year 2016, with incremental improvements and development of the underlying models. The results of the latest assessment are reported alongside previous results in Table 7.

Table 7 Characterisation results of the management of e-waste, as reported over time.

	Cimate change *kg CO_2e*	**Energy demand** *MJ NCV*	**Particulate matter** *g $PM_{2.5}$-eq*	**Water scarcity** *m^3-eq*
FY24	-2,071	-25,655	-2,898	-451.2
FY23	-1,933	-25,403	-3,002	-191.9
FY22	-1,358	-16,669	-2,374	-4.1
FY21	-1,467	-19,012	-2,503	-2.6
FY20	-1,268	-19,464	-2,016	-2.1
FY19	-1,202	-17,483	-1,691	-6.1
FY18	-1,357	-20,770	-1,115	-11
FY17	-1,209	-21,700	-914	-8
FY16	-981	*NA*	*NA*	*NA*

Overall, results remain stable compared with the last iteration. However, we note a significant variation in terms of water scarcity, which will be discussed in Section 4.5.

4.2 Climate change

Overall, recycling 1 tonne of mixed television and computer waste collected in Australia was estimated to save 2,071 kg CO_2e from being emitted to the atmosphere. This is equivalent to planting 34 tree seedlings grown for 10 years[1].

Most impacts are linked to downstream reprocessing, representing 86% of climate change impacts. Logistics are comparatively low, representing about 7% of emissions. The overall burden is entirely compensated by the benefits associated with avoiding the production of virgin materials.

Ferrous metals (iron) represent close to half of the benefits, with 45% of the total. We note that the benefits of aluminium and copper recovery is lower than in FY23, which is linked to smaller fraction being reported by recyclers. These three base metals represent together two-thirds of total benefits. They can easily be segregated using current technologies, such as magnetic separator and eddy current separators. They also have good resale value and well-established recovery routes, and they replace material that require significant amounts of energy to be produced from raw ore.

In this analysis, the recycling of precious metals provides substantial benefits, representing 16% of the total benefit.

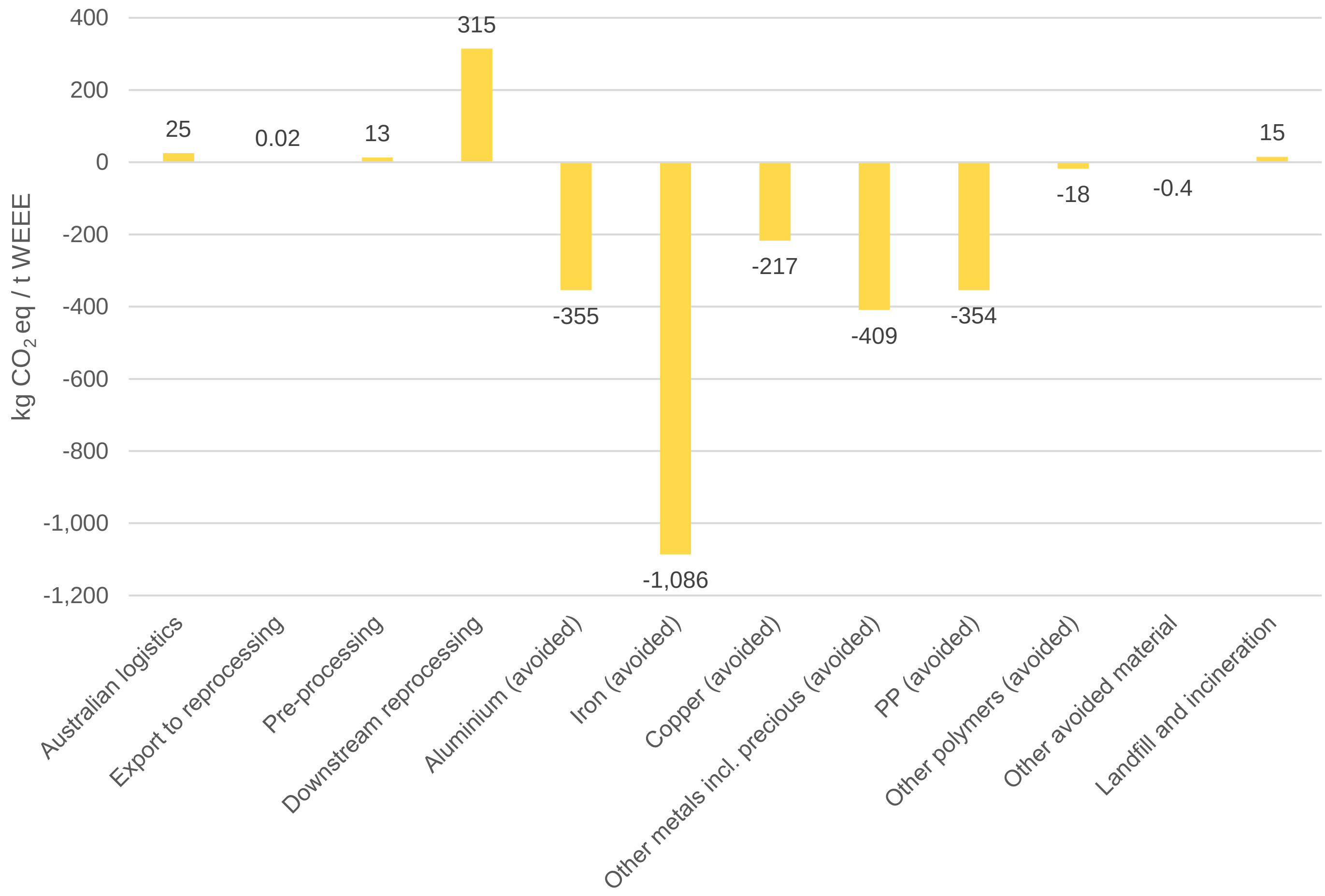

Figure 6 Climate change characterisation results, broken down by steps.

[1] Based on modelling assumptions developed by the U.S. EPA in their Greenhouse Gases Equivalencies Calculator, **https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references**

4.3 Energy

Overall, recycling 1 tonne of mixed television and computer waste collected in Australia saved 25,655 MJ. This energy could supply electricity to an average Australian household for 104 days[2].

As with climate change, most of the energy use lie in the downstream reprocessing of the various fractions, representing 87% of all energy use. Comparatively speaking, the logistics associated with collecting waste represents 9% of energy consumption.

This effect is compensated by the benefits associated with avoiding the production of virgin materials. Base metals, including iron, aluminium and copper provide significant benefits in terms of energy savings, with 56% of the total when combined. These materials are present in substantial amounts in the waste, and their production from raw material requires significant amounts of energy.

The benefits associated with plastic recycling is also significant in FY24, representing 28% of the total benefits.

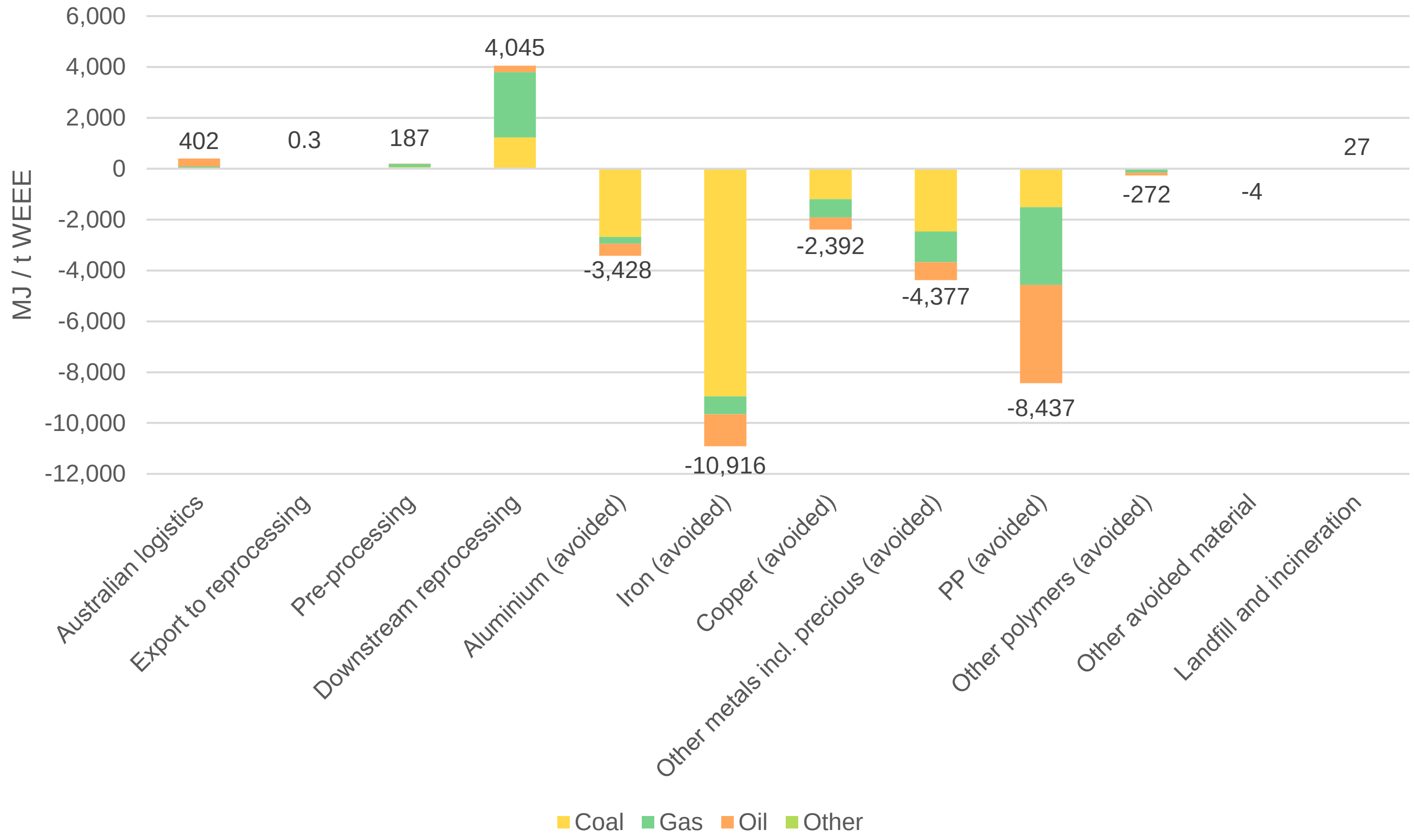

Figure 7 Energy demand characterisation results, broken by steps.

---

[2] Based on 90 GJ of annual energy per Australian household in FY22, using Australian Bureau of Statistic data (**Energy Account**)

4.4 Particulate matter

Overall, recycling 1 tonne of mixed television and computer waste collected in Australia saved 2,898 grams of particulate matter. This is equivalent to removing over 4,299 km of truck travel[3].

The emission of particulate matter, globally, has significant health consequences. This is particularly the case in densely populated areas, and in countries with lower emission controls.

The energy input from downstream reprocessing is responsible for over 90% of particulate matter emissions. Most of the rest (6%) is associated with transportation of e-waste from their point of collection to each recycler.

As with other impact categories, these burdens are more than compensated by avoided materials, and the base metals iron, copper and aluminium together represent close to 80% of the avoided emissions.

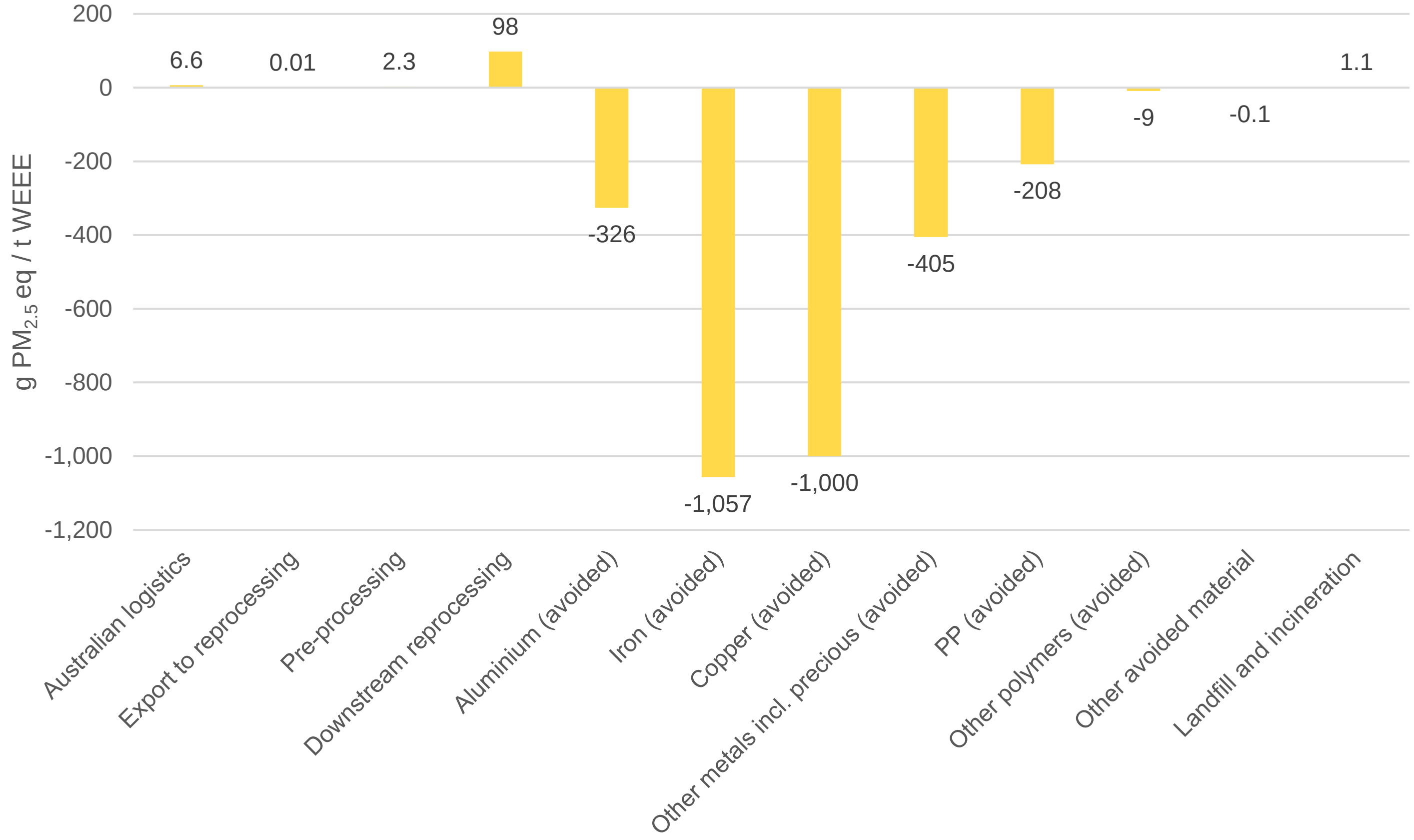

Figure 8 Particulate matter characterisation results, broken down by steps.

---

[3] Based on an EURO3 diesel truck emission as modelled in ecoinvent 3.5.

4.5 Water footprint

Overall, recycling 1 tonne of mixed television and computer waste collected in Australia saved 451 m^3 eq. of water. This is equivalent to 13 days of household water use[4].

The water footprint takes account of the relative water stress in catchments where water is extracted. Estimated water savings are significantly higher than in FY23. During the FY24 update, a review of the water requirement modelling for plastic reprocessing led to a significantly lower estimate of water scarcity impacts of downstream reprocessing overall. In FY23, downstream reprocessing was estimated to contribute 483 m^3-eq per tonne of e-waste treated, while this value was revised as 132 m^3-eq per tonne e-waste.

Other aspects are well aligned with previous results, with the recovery of copper and other metals (incl previous metals) representing two-thirds of the benefits.

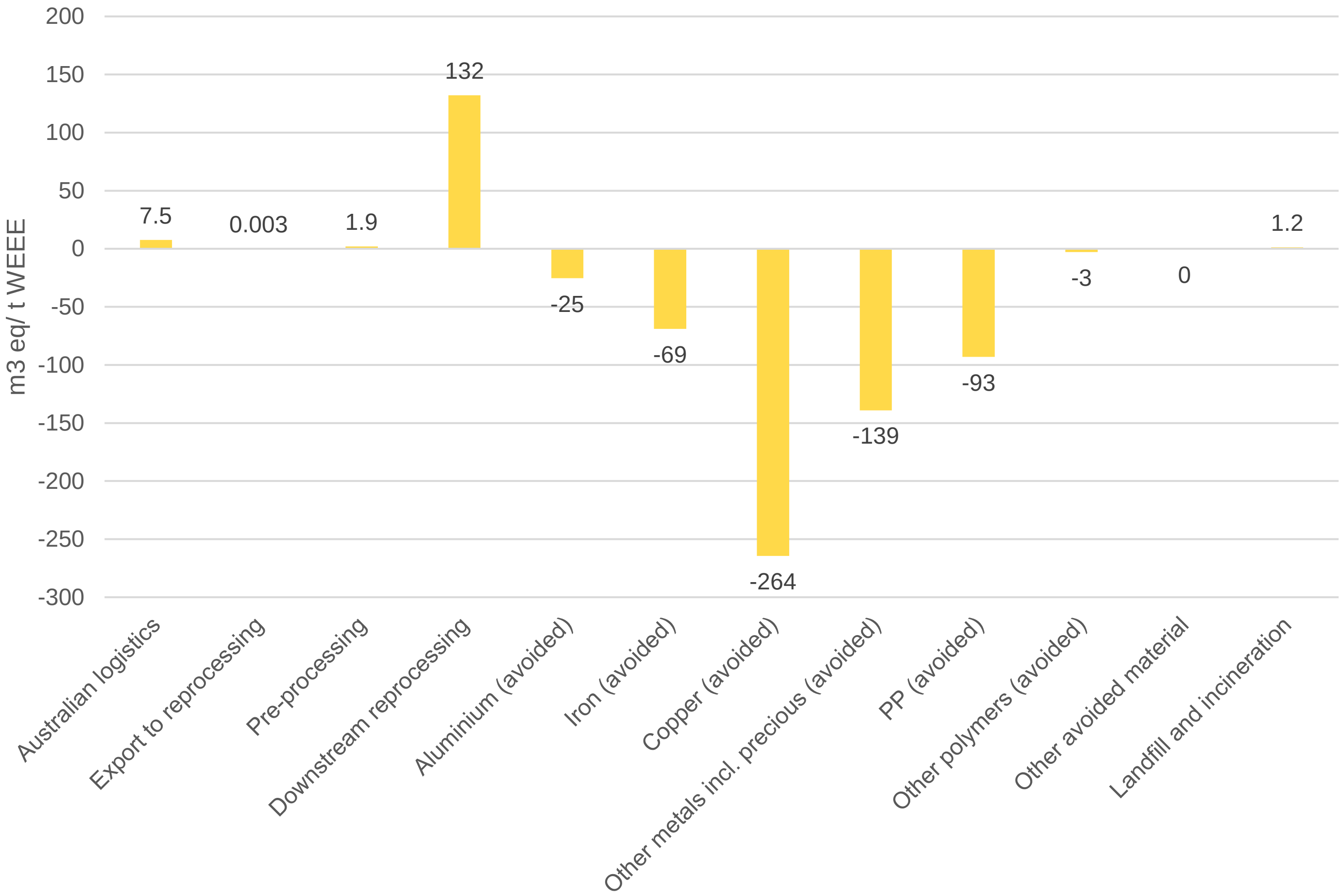

Figure 9 Water scarcity characterisation results, broken down by steps.

[4] Based on 34 m^3 equivalent per day and per Australian household in FY22, using Australian Bureau of Statistic data (**Water Account**), and the Australian average water scarcity factor as per the AWARE method [16].

5 References

1. International Organization for Standardization, *International Standard, ISO/DIS14040, Environmental Management Standard- Life Cycle Assessment, Principles and Framework*. 2006: Switzerland.
2. International Organization for Standardization, *International Standard, ISO/DIS14044, Environmental Management Standard- Life Cycle Assessment, Requirements and Guidelines*. 2006: Switzerland.
3. International Organization for Standardization, *International Standard, ISO 14044, Environmental Management Standard- Life Cycle Assessment, Requirements and Guidelines*. 2006: Switzerland.
4. ISO, *International Standard ISO 14044. Environmental management - Life cycle asessment - Requirements and guidelines*. 2006: Switzerland.
5. ALCAS, *Australian Life Cycle Inventory Database (AusLCI) Version 1.40*, A.L.C.A. Society, Editor. 2022: Melbourne.
6. Weidema, B.P., et al., *Overview and methodology. Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1(v3.10)*. 2023, The ecoinvent Centre: St. Gallen.
7. Weidema, B.P., et al., *Overview and methodology. Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1(v3.9.1)*. 2022, The ecoinvent Centre: St. Gallen.
8. Oguchi, M., et al., *A preliminary categorization of end-of-life electrical and electronic equipment as secondary metal resources.* Waste Management, 2011. **31**(9): p. 2150-2160.
9. Schwartz, E., et al., *Comparative life cycle assessment of copper and gold recovery from waste printed circuit boards: Pyrometallurgy, chemical leaching and bioleaching.* Journal of Hazardous Materials, 2024. **473**: p. 134545.
10. Nishtala, S. and E. Solano-Mora, *Description of the Material Recovery Facilities Process Model. Design, Cost and Life Cycle Inventory. October 1*. 1997, Research Triangle Institute and North Carolina State University: North Carolina, USA.
11. Grant, T., et al., *Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria*. 2001, Centre for Design at RMIT University; Centre for Packaging, Transportation and Storage at Victoria University; and Centre for Water and Waste Technology at the University of New South Wales: Melbourne. p. 172.
12. Berglind, J. and H. Eriksson, *Life cycle assessment of toner cartridge HP C4127X, Environmental impact from a toner cartridge according to different recycling alternatives*. 2002, Department of Technology, University of Kalmar. p. 45.
13. ACS. *Pulling iron out of waste printer toner*. 2017; Available from: **https://www.acs.org/content/acs/en/pressroom/presspacs/2017/acs-presspac-november-15-2017/pulling-iron-out-of-waste-printer-toner.html**.
14. Fisher, K., et al., *Battery waste management life cycle assessment*. 2006, Department for Environment, Food and Rural Affairs.