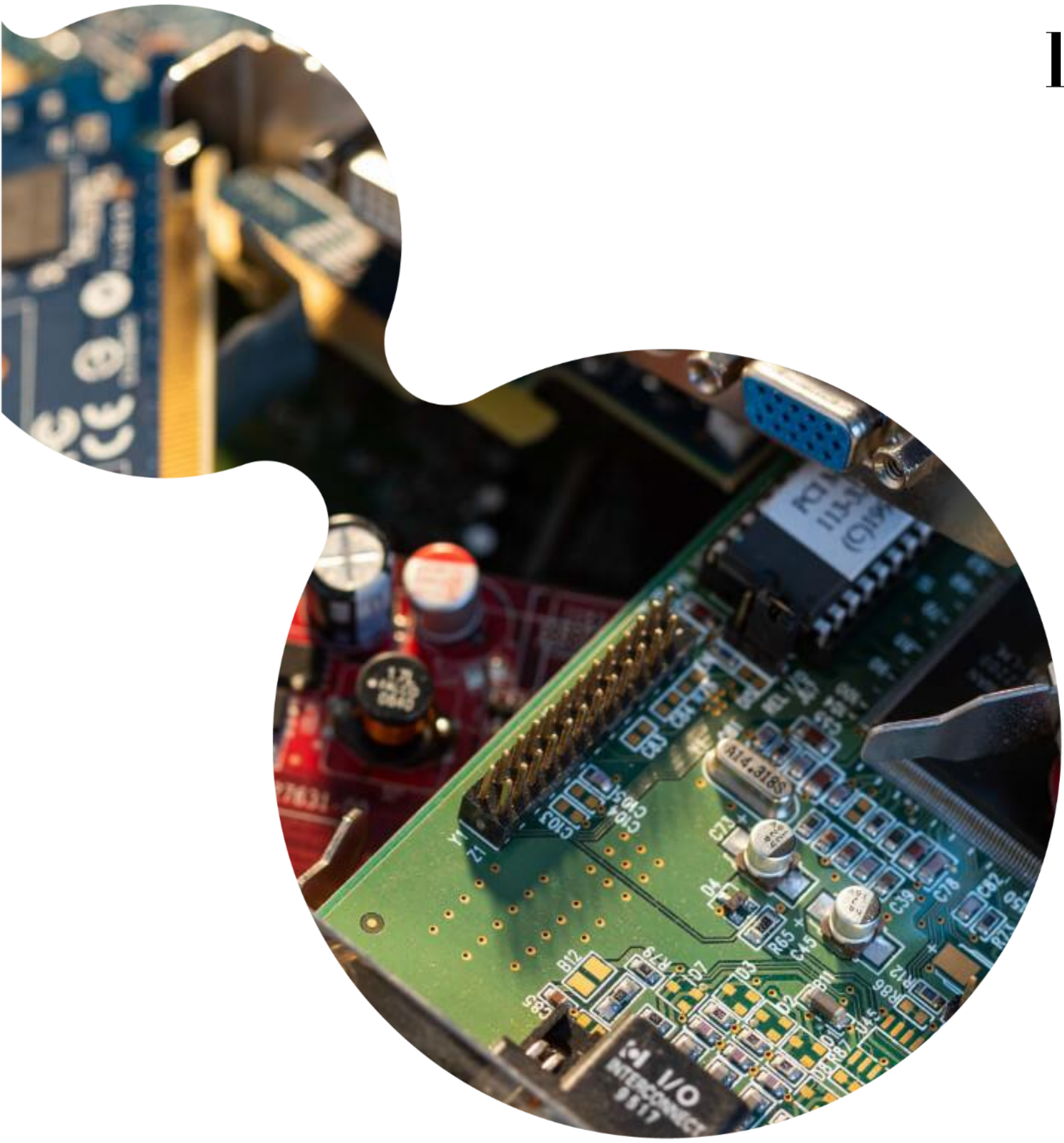


Potential environmental benefits of ICT e-waste recycling in Aotearoa New Zealand

Undertaken by Lifecycles
For the TechCollect NZ pilot programme
July 2022

Contents

Bontinck P.A. (2022), *Potential Environmental Benefits of ICT e-waste Recycling in Aotearoa New Zealand*. Lifecycles, Melbourne, Australia.

Context

TechCollect NZ (TCNZ) is a New Zealand not-for-profit member-based organisation who provides a free collection and recycling service for information and communication technology (ICT) e-waste in Aotearoa New Zealand. TCNZ partner with local service providers who meet stringent health, safety, and environmental standards.

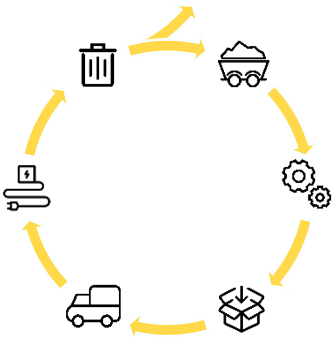
TCNZ's national service was launched as a pilot programme in November 2018 and has recovered over 171 tonnes of ICT e-waste for recycling to date (as of 30 June 2022).

This analysis explores the potential benefits of TCNZ's national programme, building on the work conducted with the Australia and New Zealand Recycling Platform (ANZRP[1]) annually, since 2016. It adapts the Australian model to the New Zealand context, using information provided by TCNZ and their programme partners.

It will help provide a baseline of environmental benefits and outcomes achieved to TCNZ, identify key strengths and weaknesses of the programme, and highlight aspects to explore further to increase the benefits of the programme.

This report presents the environmental data for e-waste recovered and recycled by the TCNZ pilot programme from March 2021 to February 2022, covering the benefits of e-waste recycling on climate change, water and fossil energy use, and particulate emissions.

Life cycle assessment (LCA)



The environmental impacts and benefits have been calculated using a life cycle assessment (LCA). This methodology is used to evaluate the full cradle to grave environmental benefits of products and processes, by assessing the environmental flows at each stage of a products life cycle. Here, we focus on ICT e-waste items accepted via the TCNZ pilot programme. LCA aims to include all important environmental impacts for the product system being studied. By including all of these environmental impacts, the study results avoid shifting impacts from one life cycle stage to another and from one environmental impact to another.

The framework and principles of LCA are described in the international standards ISO 14040[1] and specific requirements for LCA are provided in ISO 14044[2].

The assessment follows four stages:

- **goal and scope,** describing the reasons for the LCA, and the scenarios, boundaries, indicators and other methodological approaches used.

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[1] ANZRP is a not-for-profit Co-regulatory arrangement that has been operating Australia's National Television and Computer Recycling Scheme (NTCRS) since it commenced in 2012.

- **inventory analysis**, where a model of the production systems involved in each of the scenarios, and how each stage in the production process interacts with the environment, is built.
- **impact assessment** relates the inventory data to impact indicators, to produce an environmental profile for each scenario.
- **interpretation**, where the results are analysed, and systematic checks of inventory data and assumptions are undertaken to determine the robustness of the results.

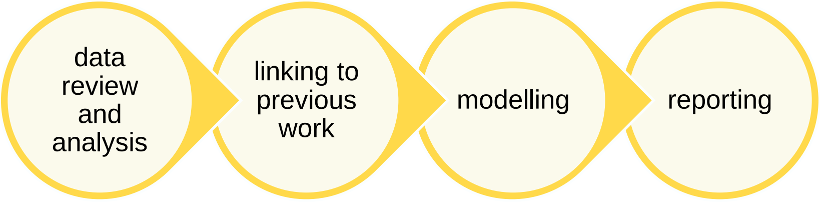
Our approach

The objective of this project was to understand and quantify the potential environmental benefits of the TCNZ pilot programme. This was done by modifying an existing model developed for ANZRP, using relevant data provided by TCNZ and their partners. Information relative to volume of in-scope ICT e-waste items collected, logistics networks and downstream processing of the ICT e-waste was collected for this study, while the existing model representing each step in the recycling process was reviewed and tailored to this analysis in the Aotearoa New Zealand context.

For instance, processes taking place in New Zealand were modelled based on data developed for the Australian context, which were modified to consider key aspects such as the local energy mix.

Inventory data is representative of the ICT e-waste recovered and recycled by the TCNZ pilot programme.

As illustrated below, the project was divided into four phases including: data review and analysis, linking to previous work, modelling, and reporting.



Phase	Description
Data review and analysis	- Review and analyse all inventory data provided, assessing how best to apply it to the LCA model.
Linking to previous work	- Assess the existing Australian models to ascertain which section need to be reviewed to be representative of the New Zealand context.
Modelling	- Calculate and model the logistics of TCNZ activities. - Calculate and model the downstream management of the e-waste by TCNZ's service partners.
Reporting	- Document results, including all assumptions, in accordance with ISO 14040.

Goal and scope

Goal

The goal of this analysis is to quantify the environmental impacts and benefits associated with recycling ICT waste, including the transportation and reprocessing of used equipment as well as the replacement of virgin material by recovered materials in the e-waste items recovered by TCNZ's pilot programme.

Functional unit

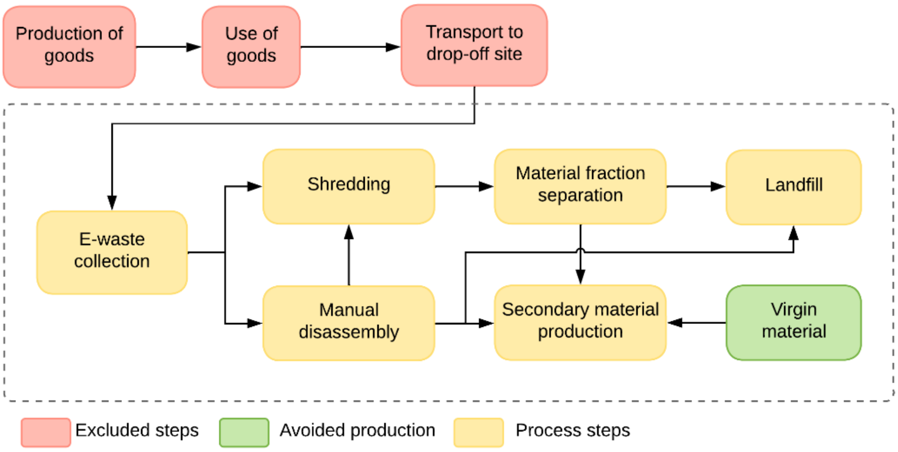
The international standard on LCA describes the functional unit as defining what is being studied, and states that all analysis should be relative to the functional unit. Its definition needs to clearly articulate the functionality or service that is being investigated.

In this case, the service being investigated is the management of ICT e-waste by TCNZ. Thus, the functional unit is defined as:

"the collection and recycling of 1 tonne of mixed ICT waste collected and recycled by TCNZ's pilot programme in Aotearoa New Zealand".

System boundary

The system boundary describes the life cycle stages and processes included in the LCA. In this study, the function analysed is the management of ICT waste, as described in the Figure below.



Typically, system boundaries should include everything that is substantially affected by demand for the service provided. This includes extraction and production processes, and any additional activities required by the system being analysed.

The system boundary may exclude elements that fall below a cut-off threshold. In this case, the production and use of electronic goods is considered irrelevant to the recycling processes. Thus it is excluded from this assessment.

Inventory analysis

Inventory analysis is the stage of the LCA where the system studied is broken up into unit processes. For each unit process, the flows are defined per unit of output. These included flows to and from the environment and flows to and from the technosphere. All flows are defined relative to the functional unit.

Foreground data represents information provided directly by or calculated from information provided by TCNZ. These include the breakdown of materials recovered, the transport logistics associated with the management of ICT e-waste by TCNZ, both from the original point of collection to the recyclers, and downstream until a secondary commodity has been produced or a residual waste stream has been discarded.

Background data covers information sourced from the literature or existing Life Cycle Inventory databases. These include all processes involved in the recovery of materials from e-waste. In detailing the breakdown of material fractions sourced from e-waste collection, a mix of foreground and background data was used. For instance, the average mix of metals in PCBs was sourced from the literature[3]. A major source of background data is AusLCI[4], which is the Australian national initiative to develop life cycle inventory data. When used, these models were modified to suit the local context.

Inbound e-waste logistics

The Recycling Group is the sole recycler involved in the programme to date. Its main operation is Auckland, though pre-processing occurs at a second site in Christchurch, which also used to consolidate ICT e-waste collected from the South Island. The total distance travelled between the collection points and the recycler was calculated using information shared by TCNZ and their service partners.

Road freight is the principal transportation mode used to carry e-waste from their original collection to the recycling facilities, although some sea freight is required to transport waste between the North and South islands of Aotearoa.

Linking this information with a matrix of distances between collection points and recycler facilities allowed to model this first logistical step in detail. Logistics was weighted based on the tonnage of e-waste collected in the period of reference.

In LCA, freight efforts are modelled using a tonne.km unit, which represent the requirements of moving 1 tonne of goods over 1 kilometre.

Parameter	Unit	Value
Road freight	t.km	20,405
Sea freight	t.km	11,928
Average road distance per tonne of waste	km	281

Logistics of overseas export

Based on the information collected, approximately 71% of the total mass of material collected is processed in New Zealand, up to the point that it becomes a secondary commodity sold to local and global markets.

Of the four destination countries reported, Malaysia (73%) and Japan (19%) represented 92% of the total export.

Some materials are more typically exported than others. For instance, 100% of printed circuit boards (PCBs) are sent to Japan – a country that has heavily invested in the development of technologies to reprocess PCBs.

Similarly, the inventory data confirms that plastics recovered from recycled e-waste processed by The Recycling Group are exported to Malaysia.

Other materials are typically managed in New Zealand. Glass, for instance, is entirely managed domestically, which can be explained by its very low (or negative) value on the international market. This is at the exception of leaded glass, which is exported to Australia to be processed in a smelter to recover the lead fractions. Metals (ferrous and non-ferrous) are generally recovered in New Zealand and sold on the global market as secondary material.

Country	Proportion %	Mass exported kg	Typical materials
Malaysia	73%	15,389	Plastics (67%), and toner (33%)
Japan	19%	3,931	Printed circuit board (100%)
South Korea	4%	869	Batteries (100%)
Australia	4%	837	Lead glass (100%)

Material fractions in e-waste

A critical aspect of this analysis is to understand the material composition of a tonne of the ICT e-waste managed by TCNZ. The most significant potential for environmental benefits associated with recycling systems resides in the recovery of individual material fractions. Indeed, when recovered, these materials can replace virgin materials, thus avoiding their production in the first place.

There is a broad range of materials in e-waste, including various metals and plastics, and glass. Metals are often a focus of the recovery effort, as they represent a high proportion of typical e-waste materials, can sometimes be easily separated, and have a high resale value.

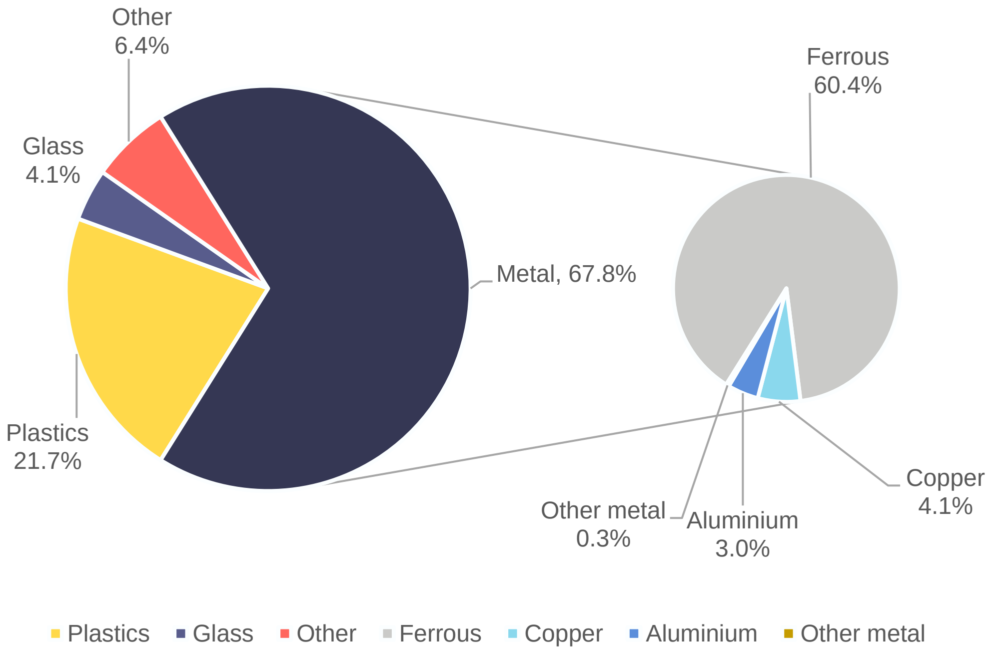
Some companies have developed expertise in the recovery of valuable materials from specific sub-streams of materials, like PCBs, toner or batteries.

In this study, information provided by TCNZ was used to identify the material fractions found in ICT e-waste recovered by the national pilot programme. This information relies on an analysis of a sample of 1.2 tonne of e-waste treated by The Recycling Group, as a representation of the entire stream.

Material fraction	**Mass *kg / t***	**Ratio %**
Metal	**678**	**68%**
- Aluminium	30	2.99%
- Brass	2.7	0.27%
- Copper	41	4.11%
- Gold	0.0014	0.00%
- Iron	604	60%
- Nickel	0.18	0.02%
- Palladium	0.00043	0.00%
- Silver	0.019	0.00%
Glass	**41**	**4%**
- Clean glass	30	2.99%
- Lead glass	12	1.15%

Material fraction	**Mass *kg / t***	**Ratio %**
Plastics	**217**	**22%**
- Mixed plastics	44	4.39%
- ABS/PC	119	11.93%
- PS	54	5.36%
Other	**64**	**6%**
- Landfill	39	4%
- Batteries	12	1.20%
- Toner	13	1.30%

The overall material breakdown is summarised in the diagram below.



Reprocessing steps

PRE-PROCESSING

Pre-processing was modelled using data published by Bigum, Brogaard et Christensen[3], reported in the table below.

Input	Value *kWh/t*	Comment
Electricity	66	The only input reported is the electricity required to run the process. Emissions to air are reported, but not relevant to the indicators assessed and therefore are not included.

The ICT e-waste collected is either manually disassembled or directly shredded or granulated. This process takes place at the two facilities run by The Recycling Group. The inventory data confirmed that a majority of the e-waste is manually disassembled and forwarded to downstream processors for further refinement, in some cases offshore. The exception to that are PCBs and hard drives which are shredded and plastics, which are granulated.

Overall, approximately 21% of all waste was estimated to be shredded or granulated. The separated fractions are then sent to downstream recyclers for further processing.

Our model assumes that manual disassembly does not require energy input. While workers will typically use power tools requiring electricity for this task, the energy consumption is considered to be insignificant for the purpose of this analysis.

RECOVERY OF MATERIAL FRACTIONS

Material recovery includes the treatments each fraction goes through to recover secondary material. Our model stops at the creation of a secondary stream, which is then sold on the local or global markets. A summary of high-level modelling assumption is provided for each fraction in the table overleaf.

The total fraction of e-waste which is exported for further treatment was estimated based on information supplied by TCNZ. Of the total volume of material collected during the year, 21 tonnes or 29% was exported for further treatment. This principally concerned PCBs, clean plastic streams, batteries, and lead glass.

The Recycling Group provided 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 the year.

Fraction	Location	Process	Comment
Ferrous metal	NZ	Modified AusLCI recycling process	Process modified to use the New Zealand energy mix. Material offset is represented by the global supply.
Non-ferrous metal	NZ	Modified AusLCI recycling	Process modified to use the New Zealand energy mix. Material offset is represented by the global supply.
Plastics	MY	Modified Australasian LCI database	Energy from Grant et al.[5] adjusted to the energy mix in Malaysia. Material offset is represented by the global supply.
Toner	MY	Previous LCA work	Toner reprocessing, as conducted in Malaysia, is represented by previous work conducted by lifecycles on a process taking place in Australia, modified to use the energy mix of Malaysia.
Battery	KR	Previous LCA work	Adaptation of work conducted at lifecycles on the recycling of cell phones[6]. The model assume that lithium battery would form the vast majority of the chemistry collected.
PCB	JP	Bigum, Brogaard et Christensen[3]	Modelled from the literature.
Landfill	AU	AusLCI landfill process	Unmodified.
Glass	NZ	Modified Australasian LCI database	Due to uncertainty, only half the glass is assumed to be reprocessed as glass, the rest is assumed to be used in other application. In that case it is modelled to displace sand.
Lead glass	AU	Modified ecoinvent lead smelting process	ecoinvent[7] model, modified using data from Nyrstar.

METALLURGICAL RECOVERY OF METALS FROM PRINTED CIRCUIT BOARDS

According to the available literature[3], non-ferrous and precious metals from PCBs (copper, nickel, gold, silver, palladium) can be recovered in a specialised plant which separates and refines the different metal fractions.

The steps required are described in the table below.

Input	Unit	Value	Comment
Kaldo plant			
Electricity	kWh	0.4	
Quicklime	t	0.05	
Anode refinery			
Electricity	kWh	310	
Heat	MJ	0.04	
Sulphuric acid	t	0.04	
Precious metals refinery			
Electricity	kWh	4.89	Pro-rated to the amount of precious metals mix coming out of the anode refinery process.
Heat	MJ	0.65	
Liquid oxygen	t	1.5	

One final important aspect of the recycling process is the overall recovery rate of the embedded material. Some material is always lost in any recycling process, especially when segregation is complex.

Here we focus on metal recovery rates from the processing of waste PBCs, as reported in the literature[3].

The two major steps where metals are lost are:

1. **pre-processing**, especially during the shredding process, where metal dust can be mixed with other fractions and therefore difficult to recover; and
2. **downstream recovery process**, where not all the metal can be recovered, which is linked to the limitations of recovery processes, as well as the small fractions of material to be recovered.

The table below summarises the overall recovery rates assumed during the metallurgical recovery of metals from PCBs.

Material	Overall recovery rate
Gold	25%
Nickel	90%
Silver	12%
Copper	57%
Palladium	25%

Impact Assessment

The impact assessment stage relates the inventory flows to the indicators chosen for the LCA.

The indicators selected 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 this study.

The table below describes each of the indicators chosen for this LCA and the source of the characterisation factors.

Indicator	Description	Characterisation model
Climate change	Measured 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, methane and nitrous oxide.	IPCC model based on 100-year timeframe[8].
Fossil energy use	Measured in MJ lower heating value. It includes all energy resources extracted and used in any way. It does not include renewable energy, energy from waste or nuclear energy.	All fossil energy carriers based on lower heating values.
Particulate matter	Measured in g $PM_{2.5}$. This impact category looks at the health impacts from particulate matter for PM_{10} and $PM_{2.5}$. This is one of the most dominant and immediate risks to human health as identified in the global burden of disease.	World impact plus method [9].
Water scarcity	Measured in m^3 of water equivalent. Water extracted directly from the environment, thereby competing with environmental and other human requirements for water.	The impacts of water use based on water scarcity factors developed by Pfister[10].

Impact assessment

The impact assessment stage relates the inventory flows to the indicators chosen for the LCA. This is done by classifying which flows relate to which impact indicator and then selecting a characterisation model that quantifies the relationship of each inventory type to the indicator in question.

For example, flows of carbon dioxide and methane are both known to contribute to the climate change indicator. The characterisation model chosen for this study was the 2007 Intergovernmental Panel on Climate Change 100-year Global Warming Potential model. This uses carbon dioxide as the reference substance with a characterisation factor of 1 and methane with a characterisation factor of 25 carbon dioxide equivalents. An equivalent approach is applied across all indicators. The calculation of the indicator results is the summation of all inventory flows multiplied by their relevant characterisation factors. This step is referred to as characterisation. The results are in equivalent units, such as kg CO_2eq., for each indicator.

Note: a positive value denotes an impact, while a negative value can be interpreted as a reduction of the impacts.

CHARACTERISATION RESULTS

The results of the analysis are reported alongside previous results in the table below. The results are reported for one tonne of e-waste collected and recycled by the TCNZ pilot programme.

A detailed analysis of each indicator, including an explanation of the underlying trends, is reported in the interpretation section overleaf.

Period	**Climate change** *kg CO_2 eq*	**Cumulative energy demand** *MJ NCV*	**Particulate matter** *g $PM_{2.5}$*	**Water Scarcity** *m^3 eq*
2021-22	-2,052	-28,347	-3,026	-7.4

Interpretation

CLIMATE CHANGE

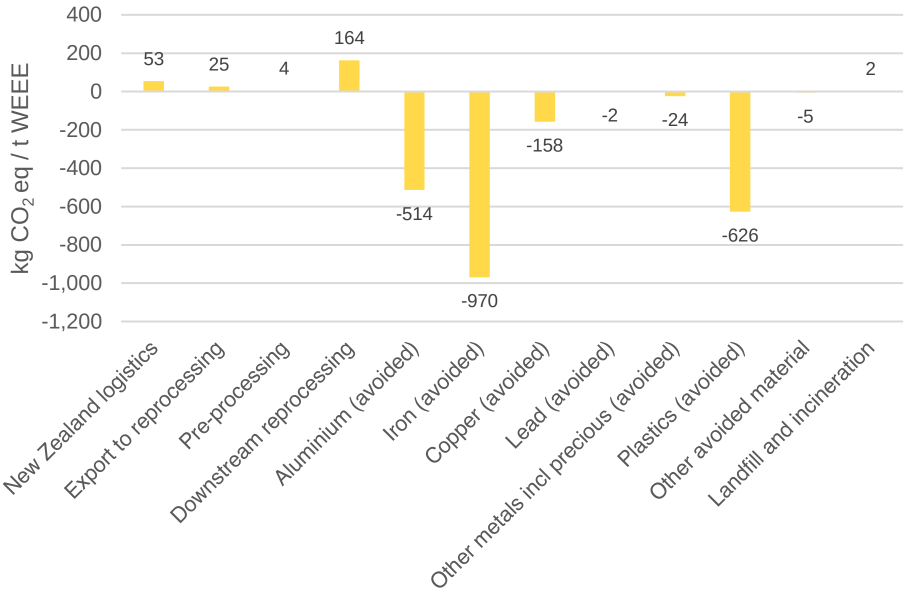
Recycling 1 tonne of ICT e-waste collected by the TCNZ pilot programme in New Zealand saved 2,052 kg CO_2e from being emitted to the atmosphere. This is equivalent to planting 30 trees[2].

The burden of transporting and processing the different e-waste material streams is entirely offset by the benefits associated with avoiding the production of virgin materials within the economy.

Most impacts are linked to downstream reprocessing, which far outweigh the emissions associated with the logistics of running the waste management system.

New Zealand has the advantage of a highly decarbonised grid, with a significant fraction of power sourced from renewable energy (hydropower, geothermal and wind). This means that processes such as metal separation and pre-processing, which mainly rely on electrical input, will result in low carbon emissions when taking place domestically.

Ferrous metals and aluminium provide 65% of the environmental benefits associated with recycling. Both fractions can easily be segregated using manual processes and current technology, such as magnetic separators or eddy current separators. They also have good resale value and well-established recovery routes and replace a material that requires significant amount of energy to be produced from raw ore.



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[2] Based on estimate of 15 trees storing 1 t CO_2e, as provided by Carbon Neutral™ (https://carbonneutral.com.au/faqs/) .

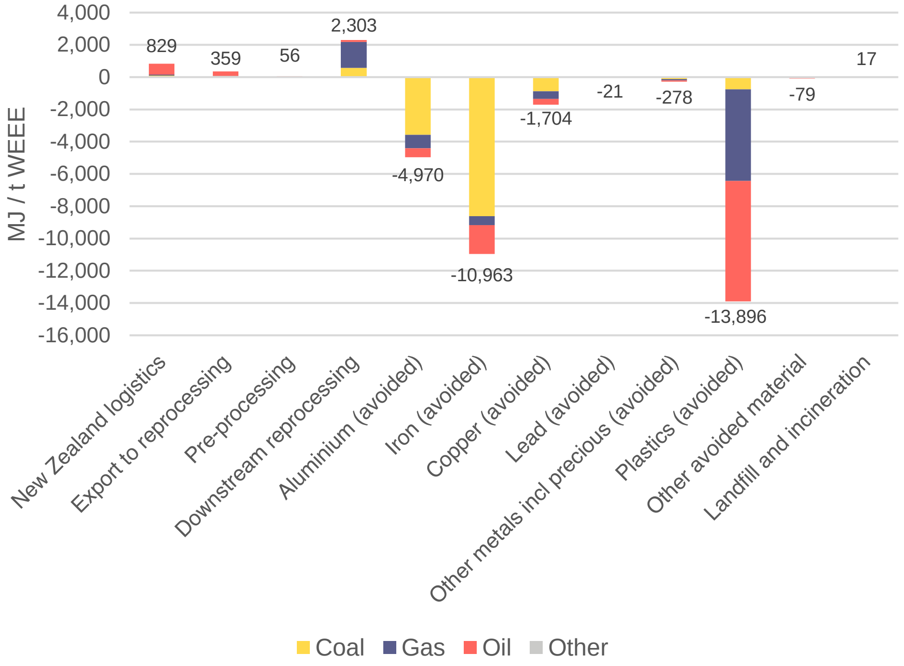
ENERGY

Recycling 1 tonne of ICT e-waste collected by the TCNZ pilot programme in New Zealand saved 28,347 MJ of fossil energy. This energy is equivalent to the electricity consumed by one average New Zealand household for 410 days[3].

As for climate change, most of the energy use lie in the downstream reprocessing of the various fractions – this includes the recycling processes associated with the various metals, plastics and glass fractions. This energy use is entirely offset by the benefits associated with avoiding the production of virgin materials.

Iron and aluminium provide significant benefits in terms of energy savings. Both materials are present in substantial amounts in the recovered e-waste, and their production from raw material requires significant amounts of energy.

The recovery of plastics as clean streams of individual polymers also provides significant benefit, avoiding the extraction and processing of oil and gas, used as feedstock to the production of polymers.



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[3] Based on 7,000 kWh of electricity consumed annually per New Zealand household in 2018, as reported by the Electricity Authority

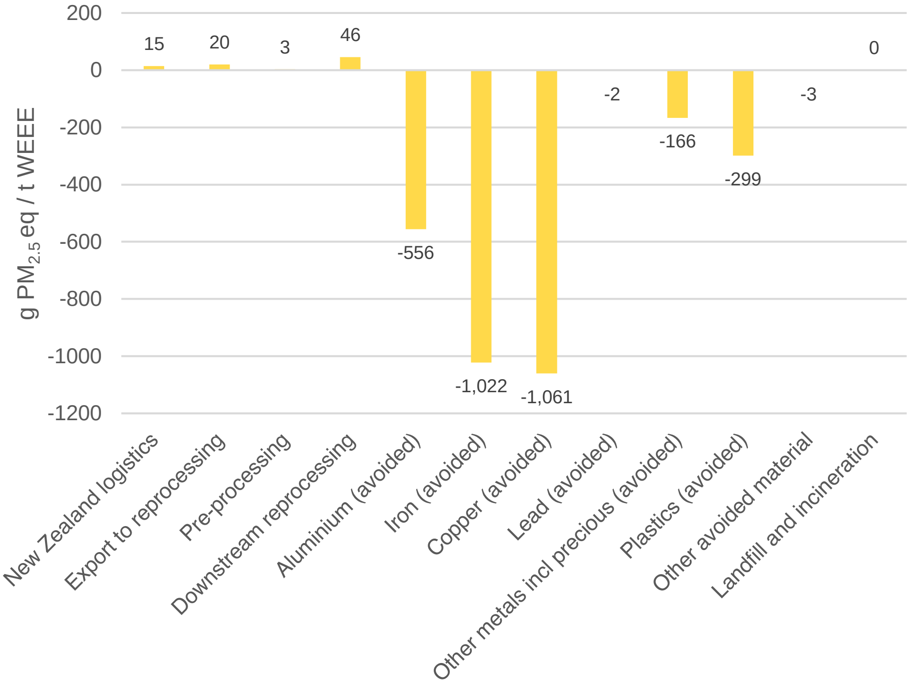
PARTICULATE MATTER

Recycling 1 tonne of ICT e-waste collected by the TCNZ pilot programme in New Zealand saved 3,026 grams of particulate matter. This is equivalent to removing over 3,050 km of truck travel[4].

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

The combustion of fossil fuel for energy production, to undertake specific processes, and for transportation, is the main source particulate matter emissions. As for climate change, we can clearly see that New Zealand benefit from an electricity grid with a low reliance on fossil fuel, as the impacts of reprocessing remain low.

The burdens associated with collecting and reprocessing the recovered e-waste are entirely offset by the production of avoided materials, particularly iron, copper, and aluminium, which are energy intensive material to produce from raw minerals.



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

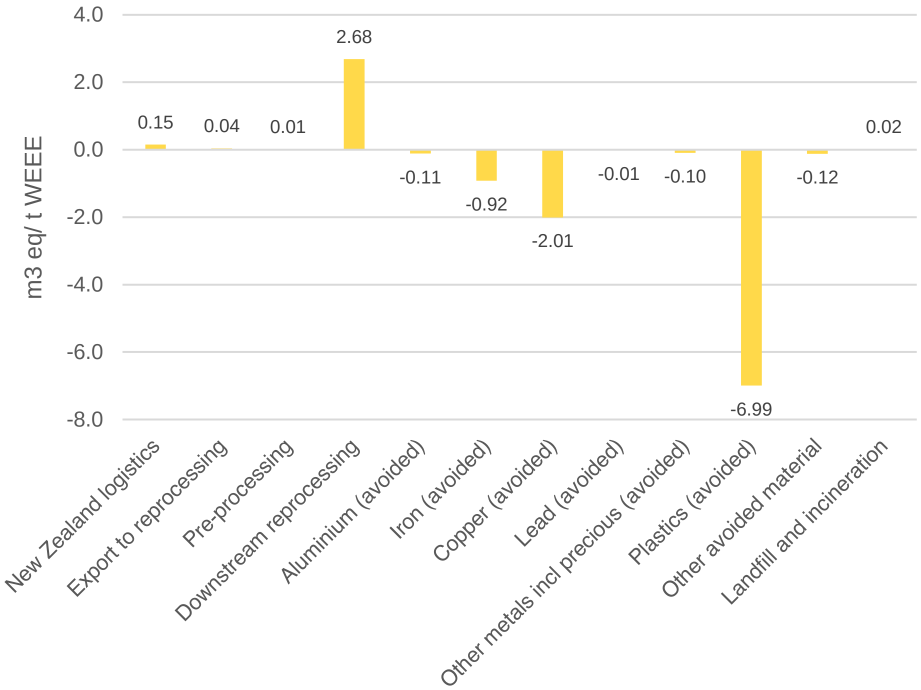
WATER FOOTPRINT

Recycling 1 tonne of ICT e-waste collected by the TCNZ pilot programme in New Zealand saved 7.4 m^3 eq. of water. This is equivalent to 26 days of water consumption for one person[5].

The water footprint takes account of the relative water stress in catchments where water is extracted. The indicator shows downstream reprocessing as being the major consumer of water, while plastic and metal recovery are the main areas of saving.

Here, the analysis highlights the benefits associated with recycling individual streams of plastics, particularly as polymers used in ICT products are high quality engineering plastics. Our analysis suggests that the recovery of ABS results in the most significant benefit on the water footprint indicator.

The analysis also reveals the benefits on water scarcity of recycling copper compared to other metals. This shows the significant water requirements associated with producing primary copper.



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[5] Based on 281 litres per day and per person in FY21, using data from Water New Zealand (National Performance Review)

Conclusions and recommendations

This baseline model provides TCNZ with transparent information on the environmental performance of the collection and recycling of ICT e-waste, as implemented by TCNZ's pilot programme in Aotearoa New Zealand.

The analysis demonstrates the clear environmental benefits associated with reprocessing ICT e-waste. It highlights the benefits of maximising the proportion of e-waste processed in New Zealand. Indeed, the country's electricity grid has a low emission profile, as a significant proportion of its electricity is produced from renewable sources such as hydro, geothermal and wind. As such, material separation processes taking place in New Zealand have low environmental impacts compared with markets which rely more heavily on fossil fuels for their energy generation mix.

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.

TCNZ collected a wealth of information during this analysis, which were combined with an extensive pre-existing model. However, as with any Life Cycle Assessment, there is room for improvement.

This analysis relies on a sample of waste to define material fractions. Though it is an entirely appropriate approach to characterise a waste stream, we would recommend collecting data representative of the entire period of analysis, if possible. Recyclers may be able to compile data on the total volume of material leaving their facility in the year, including details such as metal type (ferrous, aluminium, copper, other) and polymer type. This would help better represent the recycling programme as a whole.

Plastic recycling was highlighted as a significant source of environmental benefits. Here, collecting data from plastic recyclers in Malaysia on the applications for these recycled polymers would be helpful in modelling more accurately the benefits of plastic recycling.

As TCNZ's collection and recycling programme extends and participation increases over time, it may be required to work with a broader range of recyclers. In this case, an update to this analysis may be warranted to account for variations in practice.

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