Working Paper
There and Back Again: A Circular Tale in a CGE Model

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Abstract

As global material use is projected to double by 2060, the limitations of linear material use-patterns are becoming increasingly apparent.[1] Circular economy initiatives are emerging as critical strategies for managing future resource demand and minimising continued damages to the environment. As this becomes a larger part of the economy, the ability to model the economic impacts of a circular economy transition will be imperative for many countries.

Australia is currently preparing for a circular economy transition, with the government releasing a circular economy framework in 2024.[2] Yet to date, there are few economic analyses on the impact of this undertaking for Australia. Major behavioural changes and industry transformation will need to occur to shift Australia to a circular economy framework. Additionally, Australia currently exports 5% of its waste overseas for recycling, primarily to southeast Asian jurisdictions.[3] Key exports for recycling include paper and cardboard, plastics, and scrap metal—which alone is 64% of Australia's waste exports.[4] There has been increased attention to the negative externalities of exporting waste on the importing country. This has sparked several jurisdictions imposing bans or restrictions on waste imports, which has had negative flow-on effects throughout the region. China restrictions on importing waste in 2018 led to an increase in the amount of plastic waste being exported to southeast Asia, which consequently has driven a rise in pollution and other environmental and social concerns in this region. [5] As Australia transitions to a circular economy, understanding the economic, trade, and environmental implications, costs and benefits will help inform policy makers and industry.

A major hurdle to modelling the move toward circularity is found in traditional input-output databases. They do not traditionally account for recycling materials and the activity of recycling itself often sits within a broader parent sector, making it hard to disentangle.

To address the current gap for modelling Australia's circular economy within a Computable General Equilibrium (CGE) framework, we have developed a waste-intensity satellite database for Australia, creating a waste coefficient that follows the form of: This reflects the amount of waste (by material type) generated by each industry and each region within Australia, providing a waste intensity.

We have chosen to define waste as either 'Disposal' or 'Recovery' as an initial step, but intend to build out different waste types within Australia such as steel, copper, glass, paper and cardboard, and plastics. Using available data from the National Waste and Resource Recovery Database, we have attributed a waste intensity for each material type, industry and State/territory within our CGE database. [6] Our second step has been to disaggregate the GTAP 'water' sector to reflect two distinct sectors for the waste sector in addition to water: recovery (the collection and sorting of

[1] OECD (2019). *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences.* < https://www.oecd.org/content/dam/oecd/en/publications/support-materials/2019/02/global-material-resources-outlook-to-2060_g1g98d7d/highlights-global-material-resources-outlook-to-2060.pdf >

[2] DCCEEW (2024). *Australia's Circular Economy Framework.* < https://www.dcceew.gov.au/environment/protection/circular-economy/framework >

[3] Blue environment for DCCEEW (2025). *National waste and resource recovery report 2024.* <https://www.dcceew.gov.au/sites/default/files/documents/national-waste-and-resource-recovery-report-2024.pdf>

[4] Ibid.

[5] Ng, C.H et al., (2023). 'Plastic waste and microplastic issues in Southeast Asia'. *Frontiers in Environmental Science*. 11. <https://doi.org/10.3389/fenvs.2023.1142071>

[6] DCCEEW (2025). National Waste and Resource Recovery Database 2024. <https://researchdata.edu.au/national-waste-resource-database-2024/3798985>

waste) and disposal (to reflect landfill, incineration and other types of disposal). This will allow us to identify the additional activity and labour required in the sorting of recyclable materials, that will be used as an input into secondary manufacturing sectors, which use recycled materials.

After data collection on the cost structure (including energy inputs), we disaggregate Australia's iron and steel manufacturing sector into primary and secondary sectors, following a similar approach outlined in Chepeliev and Aguiar et al., (2022)[7].

With these adaptations to the database and model structure, we will simulate the economic impact of different measures aimed at promoting increased circularity, including subsidies, levies, productivity enhancing research and policies to encourage behavioural change. Further work will be conducted to redirect this generated waste back into secondary manufacturing sectors for our chosen commodities, reflecting the circular economy.

[7] Chepeliev, M and Aguiar, A et al., (2022). 'EU Green Deal and Circular Economy Transition: Impacts and Interactions'. Presented at the GTAP Annual Conference, 2022. <https://ageconsearch.umn.edu/record/333431/files/11130.pdf>

1 Concerning Circularity: Introduction

Global material use is projected to double by 2060 (OECD, 2019). The current linear material-use patterns which have historically been relied on will not be sufficient to sustainably meet future demand in the global economy. A prescient circular economy transition is emerging as a necessary response to traditional economic models and is being considered by multiple jurisdictions (Abu-Bakar & Charnley, 2025) (European Commission, 2026). A circular economy is a system that is designed to minimise or eliminate waste and keep resources in use for as long as possible. It centres on shifting away from the traditional economic model of take, make, and dispose and towards a system that prioritises reducing material extraction, reusing, repairing, remanufacturing, and recycling. A transition towards a circular economy represents a large-scale system and ideological change. For a circular economy to function effectively, action needs to be taken at multiple levels across the economic ecosystem:

- The micro level (products, firms, and consumers)
- The meso level (closed-loop supply chains, or establishing eco-industrial parks)
- The macro level (government policy, infrastructure, and broader economic systems) (Kirchherr, Yang, Schulze-Spüntrup, Heerink, & Hartley, 2023).

Capturing circularity in a CGE framework poses several challenges. Waste is not typically recorded as a by-product of economic activity and does not have defined producers or consumers. Furthermore, these models are built on Input-Output (I-O) tables, which do not traditionally account for recycling materials and the activity of recycling itself often sits across multiple, broader parent sectors, making it hard to disentangle. As successful circularity requires co-ordination across all levels, having visibility over these industries (i.e., waste collection, waste disposal, material sorting) is essential in informing policy and industry in their circular transition.

This paper focuses on Australia as an example on how circularity can be integrated into CGE models. Australia is currently preparing for a circular economy transition, with the government releasing a circular economy framework in 2024.[8] Yet to date, there are few economic analyses on the impact of this undertaking for Australia, or how a global circular transition will impact Australia. The implications of glboal trading partners becoming circular are significant, with iron ore among Australia's primary exports. This necessitates a robust understanding of the implications of a circular transition within Australia, but also globally, on Australia's economy.

The remainder of this paper is outlined as follows: Chapter 2 introduces our methodological framework, Chapter 3 outlines the construction of the model database and Australia's waste satellite account, Chapter 4 details the system of equations that are currently being tested in the model code. The second half of the paper (Chapters A Shortcut to Mushrooms: Assumptions and limitations5 through 9) is intended to include scenario simulations, a discussion of results, model tests, and areas for future development. However, at the time of submission, this is still in development.

To address the current gap for modelling Australia's circular economy within a Computable General Equilibrium (CGE) framework, we have developed a waste-intensity satellite database for Australia, creating a waste coefficient that follows the form of: This reflects the amount of waste (by material type) generated by each industry and each region within Australia, providing a waste intensity.

2 Methodological Framework

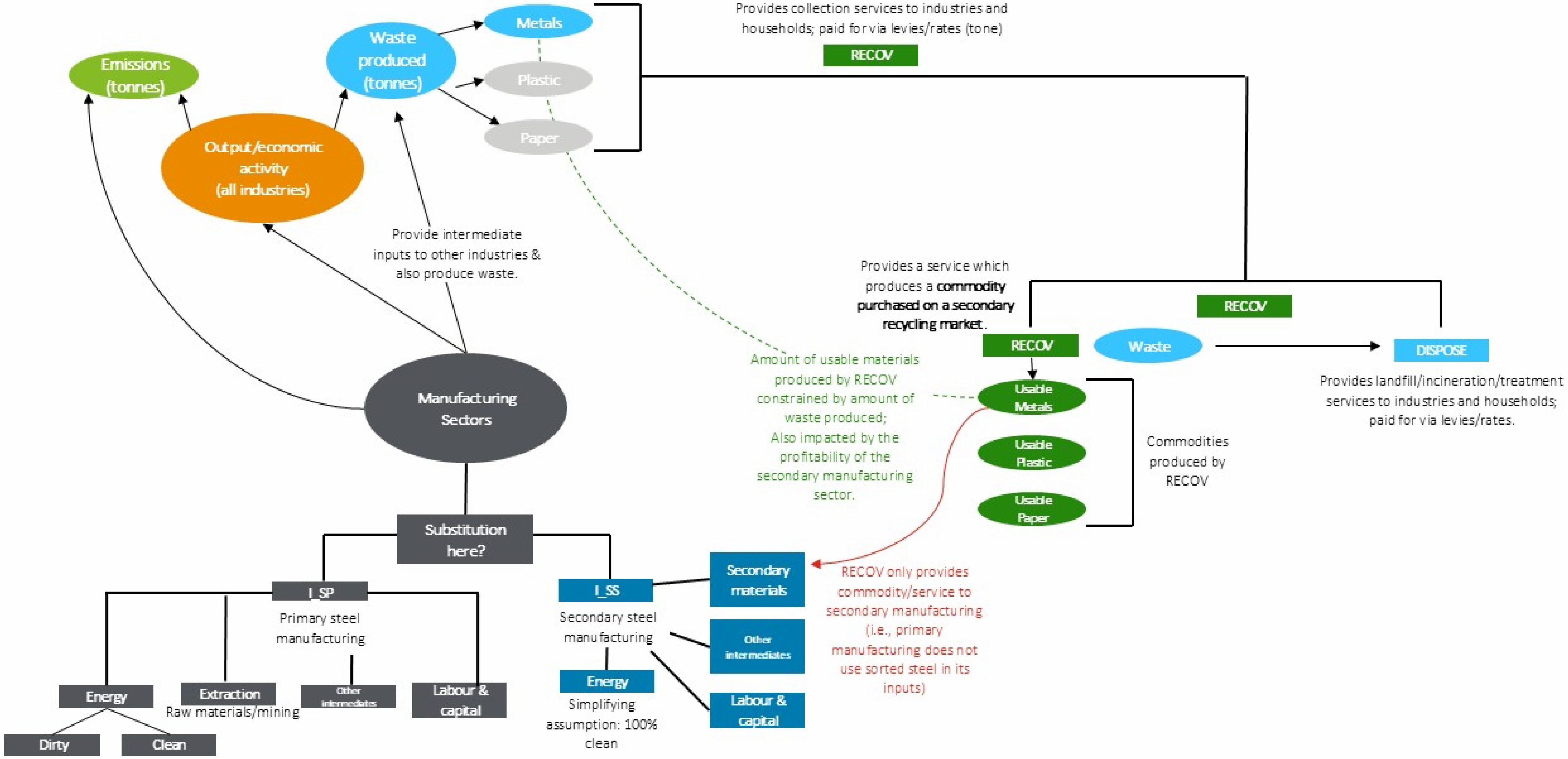
The initial motivation for this work was to determine how to represent material flows and secondary activities needed to support circularity in a CGE framework. Circularity does not happen on its own, it requires various

[8] DCCEEW (2024). *Australia's Circular Economy Framework.* < https://www.dcceew.gov.au/environment/protection/circular-economy/framework >

stakeholders to coordinate across all levels of the economy to be feasible. Representing the opportunity for a CE by improving materials productivity alone would not paint the full picture. For this work, a circular economy is defined as one in which waste is sorted, recycled, remanufactured, and used as an input into manufacturing, minimising the pressure placed on demand for primary materials.

Our first step was to develop a waste-intensity satellite database for Australia, creating a waste coefficient that follows the form of: This reflects the amount of waste (by material type) generated by each industry and each region within Australia, providing a waste intensity (Figure 1). This is reflected in the top left-hand side of the diagram below. This behaves similarly to the emissions satellite account, whereby waste is produced in response to economic activity within the model.

Figure 1: Circular Methodological Framework



This account will allow us to define waste by material type (e.g., metals, platics, paper) in the future. As an interim measure, we are defining waste only as "Recovery" and "Disposal" while the method and model is tested. The data used to define these waste types are outlined in Chapter 3.

Our methodological framework keeps the disposal, collection, and recovery of materials separate from the manufacturing process. This is necessary to reflect the micro and meso-levels required for circularity. At the micro-level, there is cost of disposal to the producer of the waste, and a sale value should the waste be sold and remanufactured. And at the meso-level, it allows us to model the sale of recovered waste through to the relevant manufacturing sectors, making a closed-loop supply chain. Further detail on the mathematical construct of this is outlined in Chapter 4.

In this model, 'Recovery' is defined as: the collection of waste and the sorting of materials. Once the waste is collected by the Recovery sector, it will either be diverted to our 'Disposal' sector (representing the treatment of waste, which can include landfill, incineration, and treatment of waste for compost or energy), or the materials will be sorted to be resold as an input into the secondary manufacturing sectors.[9] In this framework, Recovery only sells to the defined secondary manufacturing sector. Disposal only sells to the Recovery sector.

The outputs of the Recovery sector are constrained by:

- Amount of waste produced in the first instance (that is, it cannot produce more output than waste is produced)
- Assumptions around Australia's current material recovery rate and assumed maximum circularity
- Demand/availability of the secondary manufacturing sector in Australia

As a starting point, we have focused on a single commodity/sector: Iron and steel manufacturing. More commodities and secondary markets will be built into the model pending testing and potential improvements in future data availability.

3 Database

Constructing the database for this model required several sectoral splits in addition to the construction of the waste satellite account.

We begin with a version of the GTAP 11 database, with highly aggregated regions (Table 3.1) and 19 sectors. From these, two commodity-splits are performed to identify the waste sector and our recycling sector. Our final model build has 22 industries (Table 3.2). In this paper, 'Recycling' refers to the manufacturing of iron and steel products made from recovered materials, not the act of recovering recyclable waste.

The first commodity-split disaggregates the parent GTAP Water sector into: Recovery (RECOV), Disposal (DISPOSE), and Rest of Water (ROWATER). This split was informed by multiple sources, including the Australian I-O tables, which provided the data required to disaggregate water from waste. The cost structure and size of the Recovery and Disposal sectors were informed using data from IBISWorld reports and desktop research.

The second commodity-split disaggregates the parent GTAP I_S sector into primary manufacturing (I_SP) and secondary manufacturing (I_SS), following an approach outlined by Winning et al., (2017). The cost structure for these sectors partially sourced from Winning et al., (2017) who provide these figures for Australia's primary and secondary steel manufacturing sectors. The sectors from this paper were mapped to those from our model and the proportional cost structures were then applied, with several differences.

[9] Disposal is defined as the Treatment and Disposal ISIC 382 sector, which sits within the GTAP Water sector.

Unlike Winning et al., (2017) our approach does not have a 'rss' sector, and we have also made several simplifying assumptions around the energy use and inputs for our sectors, which are outlined in further detail in Chapter 5. Winning et al., (2017) have an 'other costs' sector in their paper; to distribute this portion across our model, we used the proportions from the underlying GTAP database.

The size of the sectors (i.e., how we split the I_S) were determined from IBISWorld reports on the size of these sectors in Australia. Further detail on the cost structures for these sectors will be provided in the Appendices of the final submission.

While this model's primary purpose is to model circularity for Australia, we have isolated three other regions in the database: China, APAC, and Rest of World. China was chosen as the only individual country due to its trade relationship with Australia, and its increasing focus on circular economy strategies (Bleishchwitz, et al., 2022). We intend to model a policy case in which China's steel production becomes more circular, decreasing its demand for Australian iron ore exports.

Table 3.1 Region disaggregation

Model region	Description
Australia	**Australia**
China	**China**
APAC	**Asia Pacific countries**
ROW	**Rest of World**

Table 3.2 Industry disaggregation

Model industry	Description
AGRI_F	Agriculture, forestry, and fishing
Coal	Coal
OilGas	Oil and Gas
OMIN	Mining activities
OTHMAN	Manufacturing, excluding metals
P_C	Petroleum, coal products
I_SP*	Primary steel manufacturing
I_SS*	Secondary steel manufacturing
METMAN	Non-ferrous metal products and manufacturing
ELYTND	Electricity transmission and distribution
ELYCLEAN	Clean electricity
ELYDIRTY	Dirty electricity
GDT	Gas distribution and transmission
DISPOSE^	Waste treatment (i.e., landfills and incineration)
RECOV^	Waste collection and recovery (the sorting and redistributing of recoverable waste)
ROWATER^	Rest of Water
CONS	Construction
TRADE	Trade
SERV	Services
GovServ	Government services
DWEL	Dwellings

Note: The RECOV sector does not include the manufacturing of goods out of recycled materials. This sector only captures the services associated with the sorting of materials, that is then used as an input to other sectors.

*Indicates these sectors are split from the parent I_S GTAP sector

^Indicates these sectors are split from the parent Water GTAP sector

3.1 Building the satellite waste account

Explicitly defining the amount of waste produced in Australia is central to our approach. The National Waste and Resource Recovery (NWRR) database was used to determine the historical waste generation and flows for the economy (DCCEEW, 2024). The NWRR records waste generation by waste stream, in tonnes, for each State and Territory in Australia. The three waste streams are: Commercial & Industrial Waste (C&I), Construction & Demolition Waste (C&D), and Municipal Solid Waste (MSW). This database covers the period between 2006 and 2023. This means we can establish the database to correspond with the GTAP 11 reference year of 2017.

These waste streams have been mapped to the model industries, as outlined in Table X. The C&D and MSW streams were able to be mapped to individual sectors (CONS and DWEL, respectively), however there was no industry disaggregation of waste generated from the C&I stream. To over come this, we distributed the tonnes of waste in the C&I stream across all other industries in proportion to their spend on VDFA on either DISPOSE or RECOV in their underlying database. We note that this approach carries certain limitations, as it may not accurately reflect the different waste intensities of industries, however we believe their spend on these services provides a reasonable proxy.

Table 3.3: Mapping NWRR Waste Streams to Model Industries

Model Industry	Waste Stream	Model Industry	Waste Stream
AGRI_F	C&I	**ELYDIRTY**	C&I
Coal	C&I	**GDT**	C&I
OilGas	C&I	**RECOV**	C&I
OMIN	C&I	**DISPOSE**	C&I
OTHMAN	C&I	**ROWATER**	C&I
P_C	C&I	**CONS**	C&D
I_SP	C&I	**TRADE**	C&I
I_SS	C&I	**TRANS**	C&I
METMAN	C&I	**SERV**	C&I
ELYTND	C&I	**GovSERV**	C&I
ELYCLEAN	C&I	**DWEL**	MSW

This dataset also includes a 'fate' of the waste, which indicates whether or not it was sent to recycling or to other forms of disposal (such as incineration or landfill). This provides us with a baseline resource recovery rate for Australia, as well as an overall waste intensity for each industry. This dataset also breaks this down by material type, so it is possible to define waste by type (e.g., metals, paper, plastics, organics). However, this is an area of future development and has not been incorporated into our satellite waste account at present. Table X outlines the historical waste data at an aggregated level, which has been used to build this satellite account.

While our model only reflects the tonnes of waste in 'Dispose' and 'Recover, the underlying data dictates the portion of total waste that is steel diverted to recovery and subsequently our I_SS sector, in both our base and scenario cases. This minimises the risk of overstating the amount of waste that can be realistically remanufactured by the I_SS sector.

Finally, to determine the shadow price of waste, we needed a cost for disposal and a cost for recovery. The landfill/disposal costs per tonne is the average of different State/Territory disposal levies paid across Australia, of $108AUD per tonne. An average steel scrap per tonne price was also estimated by relying on various sources:

$739AUD per tonne. These costs were estimated from a scan of State/Territory disposal fee schedules and various retailers for scrap metal.

4 System of equations

The following outlines our proposed mathematical approach for capturing circularity. At time of writing, these are being tested and are subject to change, but outline our intended direction.

4.1 Production of Waste

A system which recognises that waste can be recycled to make useful products is essentially circular. We assume that every industry produces waste in proportion to its scale of operation. So, let:

(1)

Where, α*(k,j,r)* is the waste output coefficient.

K represents the type of waste (similar to emissions), in this case, Recovery and Disposal; and

r represents region.

Equation (1) means that the waste type *k* produced by industry *j* in region *r* is proportional to the output quantity (Q) of sector *j* in that region *r.* Assuming that the waste coefficient is constant (1) also means that waste grows at the same rate as the sectoral output.

The waste is to be summed across the sectors to get the regional total of waste type *k* in tonnes:

(2)

The recovery sector collects all waste types and delivers it to their respective destinations: to the landfill site (DISPOSE) or to the recycling sector (I_SS).

4.2 Recovery Sector

The output of the Recovery (RECOV) sector is measured in total tonnes of waste disposed. This means that:

(3)

Where *t* is the recovery sector.

Once the scale of the operation is determined for the recovery sector by (3), that it moves and sorts *Q* tonnes of waste, its input demand, *QF,* is determined. This adopts a Leontief function, as:

(4)

Where *i* ε DEMAND_COMM, *t* is the recovery sector, *β(i,r)* is the I-O coefficient of the recovery sector.

Since the recovery sector *t* is a price taker in all markets, its input prices are determined at the general equilibrium level of the system.

The total cost of inputs of the recovery sector, *VFA(t,r)* is given by:

(5)

Where *i* ε DEMAND_COMM.

We assume that there is a fee per tonne (LFEE) to dispose waste at the landfill site (Landfill) and there are waste levies (WLEVY) charged to the sectors. We note that these are taken as exogenous (i.e., policy variables). The recovery sector is paid a price for the recyclable waste (RWaste) delivered to the recycling sector. Under these assumptions, the zero-profit condition for the recovery sector can be written as:

(6)

Normally, the zero-profit condition determines the scale of operation (i.e., the output) of a competitive sector. However, in this case the output of the recovery sector is determined by (3), the total quantity of waste. Equation (6) determines the price the recovery sector must charge to breakeven. Given that *P(RWaste,r)* is determined by the zero-profit condition, we now look at the behaviour of the recycling or secondary sector (in our paper, this is I_SS).

If there are multiple recyclable wastes (such as steel, glass, plastics etc.,) then (6) will determine the average price per tonne of *RWaste*. Individual prices need to be determined which needs additional equations. We defer this problem until the database has been developed accordingly.

4.3 The Recycling Sector(s)

The output of the recycling sector (i.e., our secondary manufacturing sectors) is limited by the quantity of recyclable waste and its recovery rate. Because of this, we specify the output of a recycling sector as:

(7)

Where *k* represents the recycling sector (e.g., I_SS) and μ is the recovery rate of *RWaste.*

Input demands for the recycling sector is specified as:

(8)

Where φ is the respective I-O coefficient, *i* ε DEMAND_COMM.

These input demands enter market clearing conditions for the factors and commodities that determine their respective prices (from the existing model). Note that the set DEMAND_COMM excludes *RWaste.*

We assume that the output of the recycling sector is sold with the output of the respective primary sector (i.e., they are perfect substitutes). A joint market clearing condition (below) determines the market price of the product that is shared by both the primary and the recycling (secondary) sector.

The zero-profit for the condition for the recycling sector is defined as:

(9)

And

(10)

Once again, the output of the recycling sector is limited by the quantity of waste received, so the zero-profit condition (9) is free to determine the price, *P**, for the waste input that the recycling sector can pay in equilibrium.

Now, we have two prices for the recycling waste, *P* and *P** which may be different. This problem is resolved by equation (10) which determined an endogenous subsidy rate to link the two prices. This formulation remains intact even if there are more than one type of recycling sectors.

4.4 Distribution of recycled output

Now, we specify who buys the recycled output and how their demand is determined. To do so, we make several simplifying assumptions. We have already assumed that recycled outputs of I_SS are perfect substitutions of the primary outputs (I_SP). However, we assume that only the production sectors buy recycled outputs, and their distribution across sectors is the same as the primary sector output.

Let

(11)

Where j ε PROD_COMM and kp is for the primary sector for the recycled sector k.

We allocate the demand for recycled output as:

(12)

Since they share the same market price, allocation of market price value is straightforward. The joint market clearing condition can be written as:

(13)

The price that is determined by (13) applies to both primary and recycled (secondary) outputs.

5 Assumptions and limitations

There are several simplifying assumptions and limitations in our proposed approach which need to be noted. These are outlined in Table 5.1. Further detail on the general assumptions and limitations of our model will be provided in the appendices of our final paper.

Table 5.1: Assumptions and Limitations

Assumption	Description
I_SP uses only dirty electricity	The only energy source that I_SP uses in manufacturing is dirty electricity. While there are not currently any emissions included in our database, this may be an area of future development. Simplifying the energy sources allows for more seamless integration of emissions accounting in the future.
I_SS uses only clean electricity	The only energy source that I_SS uses in manufacturing is clean electricity. This is to reflect that emissions reduction is one of the goals of a circular economy (Hailemariam & Erdiaw-Kwasie, 2023). While there are not currently any emissions included in our database, this may be an area of future development. Simplifying the energy sources allows for more seamless integration of emissions accounting in the future.
I_SS use of primary resources	Realistically, there will still be a reliance on primary materials, even in a world with more circularity. This is because of assumed rising material consumption over the next three decades. As the inputs of our I_SS sector are constrained by the amount of iron and steel waste that is produced, we allow for some input use from primary sectors, to help meet demand for secondary steel if there is a lack of sufficient recovered steel as an input in the future.
Recovery only sells to I_SS and Disposal	Our model only reflects a circular economy or closed-supply loop for one type of commodity: recovered steel. As such, Recovery can only sell to this manufacturing sector, or Disposal. In reality, Recovery is likely to sell to multiple different sectors.
Households and industry only sell to Recovery, not Disposal	This is because our Recovery sector also includes waste collection. However, in reality, both firms and households are able to travel directly to a waste disposal site and pay the required cost of disposal here. For simplicity, we have removed this and

	our version of the economy shows that all waste is sold to Recovery in the first instance, which then sells to Disposal.
There is no Recovery in our intended base case scenario.	This is a simplifying assumption to test the model. In reality, we know that Australia does recover approximately 66% of it's waste, according to the NWRR dataset.
Model industry spend on VDFA as a proxy for the generation of C&I waste	The NWRR database does not provide industry level detail below C&D, C&I, or MSW. C&D streams were assumed to come from the CONS sector in our database, however the reporting for NWRR may differ here and capture other areas of the economy. Similarly, there was no industry detail on the generation of C&I waste. We assumed that the VDFA spend on DISPOSE and RECOV are indicative of the generation of waste by these sectors, in the absence of other data.
Limitation	**Description**
Waste data only for Australia	This model's intended use is only for modelling the impacts of a circular economy in Australia. However, if it was to be expanded to include waste from other global regions, other data sources would have to be used. Alternatively, the same waste intensity in Australia could be applied to other regions. However, this would assume that they have the same waste intensities/economic profiles as Australia, which in reality is unlikely to be the case.
Emissions are not currently captured	Given the importance of a circular transition to reaching emission reduction targets, not including emissions poses a significant limitation of our modelling exercises. This is intended to be included in the future as the model continues to develop.

6 Modelling scenarios

Our modelling scenarios are still being refined, but we intend to model two policy cases in addition to the base. The first will be a highly stylised simulation to frame the policy question and its relevance to Australia. Namely, the implications of increased circularity in the steel sector in China, which purchases a significant amount of iron ore exports from Australia.

Our second scenario will focus on the potential policies and incentives that would be required to establish circularity in the steel sector within Australia. This will likely be through the use of subsidies to the circular sectors (secondary manufacturing and materials recovery), taxes on waste disposal and primary resource extraction, or a combination of both.

7 Results and Sensitives

Still to be modelled at time of submission.

8 Discussion and further research

Still to be drafted at time of submission.

9 Conclusion

Still to be drafted at time of submission.

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