Environmental impact factors for products displaced from reuse

Undertaken by Lifecycles for Charitable Reuse Australia

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Introduction

1.1 Background

Charitable Reuse Australia and the NSW Environment Protection Authority partnered on a project to conduct a triple bottom line assessment of the reuse sector in NSW. This study was the first of its kind in Australia and follows the National Guidelines for Measuring Reuse [1]. As part of this study, project consultants, Rawtec, compiled a list of available Environmental Conversion Factors (ECFs) for estimating carbon, water, and energy savings from displacing products through reuse. These ECFs were peer reviewed by Lifecycles and were fit-for-purpose for the project, i.e. to estimate the high-level environmental impacts of reuse at a statewide level. However, as noted by Rawtec, the ECFs could not be used to estimate benefits at a more nuanced level (e.g. organisation or product level) given they were compiled from various studies with varying estimation scopes and methods.

Rawtec recommended a study be commissioned to develop a comprehensive and consistent set of ECFs aligned with Tier 3 categories of the National Guidelines for Measuring Reuse. Charitable Reuse Australia engaged Lifecycles to create this set of factors, aligning all factors to a consistent source of data. This report outlines the approach taken by Lifecycles in developing these factors.

1.2 Exiobase

Lifecycles selected Exiobase as the central source of data. Exiobase is a global multi-regional input-output model, which allows to model global supply chains for a range of commodities [2]. Exiobase covers 160 industry sectors, 200 product categories across 43 countries and regions (representing 95% of the global GDP). It allows to represent the global supply chains involved in the supply of many of the products needing to be represented in the emission factors list developed for Charitable Reuse Australia.

As an input-output database, Exiobase is built using trade data and is reported in million euros. One of Exiobase's key partners, 2.-0 LCA Consultants, a Danish-based consultancy, produces a modified version of Exiobase using physical units for physical commodities. It was determined that this approach was more appropriate, as it would allow to provide emission factors on a per mass basis.

The advantage of using a global input-output model, is that it allows to represent the full supply chain of products, including global trade links.

1.3 Indicators considered

The emission factors developed during the project focused on three indicators, as specified in Table 1.

Table 1 Impact categories and characterisation models of the study

Indicator	Unit	Description	Characterisation model
GHG emissions	kg CO_2-eq	Measured in kg of carbon dioxide equivalence. This is governed by the increased concentration of gases in the atmosphere that trap heat and lead to increasing global temperatures. These gases are principally carbon dioxide, methane and nitrous oxide.	IPCC model based on 100-year timeframe [3]
Water consumption	litre H_2O	Measure of total water consumption.	Sum of all flows – no characterisation model
Land use	m^2	Measure of total land occupation.	Sum of all flows – no characterisation model

2 Mapping

Charitable Reuse Australia developed 23 emission factors for specific product categories, with an additional 4 catch-all factors. These categories are aligned to Tier 3 product categories in the National Guidelines for Measuring Reuse.

The first task was to match each specific product category to the most relevant model within Exiobase. The following section describes the approach used to produce the closest representation of each product category.

2.1 Approach

As described in Figure 1, the initial mapping identified three possible configurations:

1. **One for one relationship**, where a direct and unique link could be identified. In that case, no adjustments were required, and the emission factor could be used as is
2. **One to many relationships**, meaning that a single Exiobase emission factor could be applicable to several product group. Here, the underlying model was adjusted to better represent the specific product category. For instance, in the case of knitwear and clothing other than knitwear, it was determined that the main differentiator was the use (or not) of wool. To keep modelling simple, it was assumed that knitwear used wool, and that clothing other than knitwear did not. This is of course an oversimplification of the reality but was considered sufficient to differentiate between supply chain archetypes. Thus, the modifications consisted in replacing inputs of fibre crops for wool in the knitwear model, and vice-versa for the ‘clothing other than knitwear’ product category.
3. **Many to one relationship**, which reflect a case where there is no direct link between product category and Exiobase models. In this case, we produced a model aggregating several sectors to best represent the product category. This was particularly useful for broad product categories such as ‘toys, sports, games, art supplies and bric-a-brac.

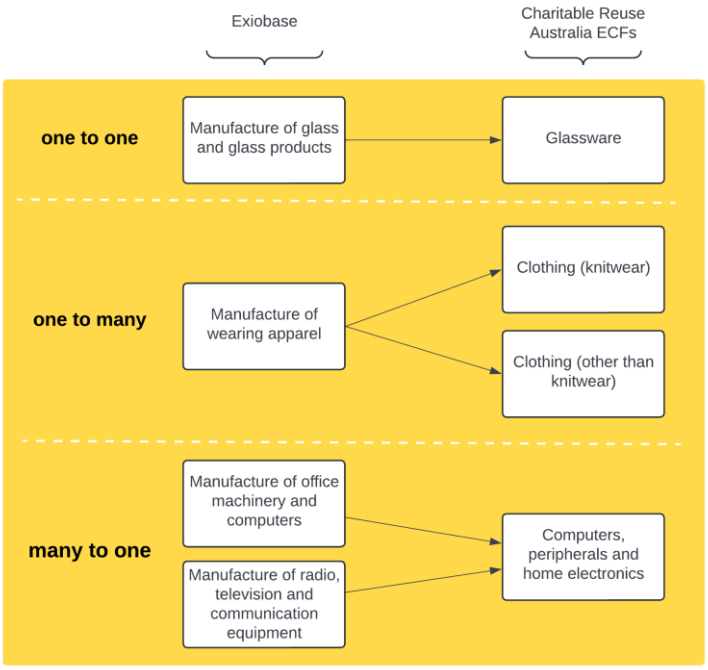

Figure 1 Matching configuration between Exiobase sectors and CRA product categories

2.2 Outcome

The outcome of the mapping process is described in detail in Table 2 below. It defines the choice of most representative sectors in Exiobase, as well as decisions made to better represent the products being represented.

Table 2 Mapping and modelling approach for each product category.

Tier 1	Tier 2	Tier 3	Mapping and modelling approach
Clothing and Textiles	Clothing	Clothing (knitwear)	The most relevant sector for clothing is the *'Manufacture of wearing apparel, dressing and dyeing of fur*', though no differentiation between knitted and other clothing. In this case, knitwear is represented as wool clothing. The original Exiobase model was thus modified to replace inputs of plant-based fibres, plastics and leather with wool.
		Clothing (other than knitwear)	Similarly to knitwear, the most relevant sector was *'Manufacture of wearing apparel, dressing and dyeing of fur*'. To represent clothing other than knitwear, we replaced inputs of wool to the sector with inputs of plant-based fibre.
		Clothing not elsewhere specified (n.e.c.)	Clothing not elsewhere specified was modelled as a weighted average of the mass of knitwear (14%) and clothing other than knitwear (86%) typically collected.
	Footwear	Footwear	Exiobase includes a sector representing leather production, as used in footwear. However, to be fully representative of the broad range of footwear product, it was decided to include other materials. As such, we developed a model aggregating three Exiobase sectors, based on an estimate of the material proportion, developed from the literature [4] as defined below: ▸ Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (13%) ▸ Manufacture of textiles (14%) ▸ Manufacture of rubber and plastic products (73%)
	Textiles	Raw textiles and fabrics	A direct match was identified in '*Manufacture of textiles*'. No modifications were implemented.
		Textile products and carpet	This product category was modelled assuming that it represents raw textiles and fabrics which have been value-added into products such as carpets, curtains, etc. It was modelled as a mix of raw textile manufacturing (80%) and apparel production (20%), to account for the additional processing required for those products.

Tier 1	Tier 2	Tier 3	Mapping and modelling approach
		Handbags and suitcases	Handbags and suitcases were assumed to be produced from a similar suit of material as footwear (leather, plastic/rubber and textiles). In the absence of specific data on the average material breakdown, it was assumed that the fraction of leather was higher (by mass) than in footwear. The proportions were defined as follow: ▸ Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (30%) ▸ Manufacture of textiles (10%) ▸ Manufacture of rubber and plastic products (60%).
		Textiles not elsewhere specified (n.e.c.)	This catch all product category was modelled as a weighted average of the mass of textile products collected: raw textiles and fabrics (1%), textile products and carpets (87%), and handbags and suitcases (12%).
Toys, games, household & homewares	Furniture	Indoor furniture	A direct match was identified in *'Manufacture of furniture, manufacturing n.e.c.'*. No modifications were implemented.
		Cushions and furnishings	The closest sector identified to represent this product was identified as *'Manufacture of wearing apparel; dressing and dyeing of fur'*. To better represent the production of cushions and furnishings, the model was modified using a larger proportion of synthetic fibres. To do so, inputs of wool were replaced with plastic product manufacturing. This assumes that cushions and furnishings are largely manufactured from synthetic fibres.
	Homewares, bric-a-brac, electronics	Glassware	A direct match was identified in *'Manufacture of glass and glass products'*. No modifications were implemented.
		Ceramics and pottery	A direct match was identified in *'Manufacture of ceramic goods'*. No modifications were implemented.
		Metal homewares, cutlery and cookware	A direct match was identified in *'Manufacture of fabricated metal products, except machinery and equipment'*. No modifications were implemented.
		Toys, sports, games, art supplies and bric-a-brac	This product gathers a range of potential product and could be considered a catch-all. In the absence of a specific breakdown of material, it was represented as a mix of sectors, including: ▸ Manufacture of furniture, manufacturing n.e.c. (5%) ▸ Manufacture of electrical machinery and apparatus n.e.c. (15%) ▸ Manufacture of rubber and plastic products (70%)

Tier 1	Tier 2	Tier 3	Mapping and modelling approach
			▸ Manufacture of wood and of products of wood cord, except furniture; manufacture of articles of straw and plaiting materials (10%)
		Books, magazines, software and video games	A direct match was identified in *'Publishing, printing and reproduction of recorded media'*. No modifications were implemented.
		Music and videos	This product category is technically included under *'Publishing, printing and reproduction of recorded media'*. However, this sector is heavily skewed towards physical printing (books, magazines, etc). However, music and videos, which include videotapes, CDs and DVDs were considered to be mostly plastic products. As such, this product category was represented as an aggregation of plastic products (90%) and the publishing sector (10%).
		Computers, peripherals and home electronics	To be representative of this broad category, it was modelled as including both computers and office machinery (e.g. printers) as well as home electronics (TV, phones, etc). Thus, the following two sectors were aggregated as follow: ▸ Manufacture of office machinery and computers (60%) ▸ Manufacture of radio, television and communication equipment and apparatus (40%)
		Whitegoods and large appliances	A direct match was identified in *'Manufacture of machinery and equipment n.e.c.'*. No modifications were implemented.
		Homewares, bric-a-brac and electronics not elsewhere specified (n.e.c.)	To reflect the range of possible products, this was modelled as aggregation of all Tier 3 products found under the *Toys, games, household & homewares* Tier 1 category as follow: ▸ Indoor furniture (57%) ▸ Whitegoods and large appliances (8%) ▸ Cushions and furnishings (2%) ▸ Glassware (3%) ▸ Ceramics and pottery (4%) ▸ Metal homeware, cutlery and cookware (3%) ▸ Toys, sports, games, art supplies and bric-a-brac (9%) ▸ Books, magazines, software and video games (9%) ▸ Music and videos (3%) ▸ Computers, peripherals and home electronics (1%)

Tier 1	Tier 2	Tier 3	Mapping and modelling approach
Other	Building materials	Wood and timber products	A direct match was identified in *'Manufacture of wood and of products of wood cord, except furniture; manufacture of articles of straw and plaiting materials'*. No modifications were implemented.
		Plastic products	The closest sector identified in Exiobase is '*Manufacture of rubber and plastic products'*. To allow differentiating between plastic and rubber products, this sector was modified, so that inputs of rubber were replaced by raw plastic resin.
		Rubber products	The closest sector identified in Exiobase is '*Manufacture of rubber and plastic products'*. To allow differentiating between plastic and rubber products, this sector was modified, so that inputs of plastic resin were replaced by rubber.
		Ferrous metal	A direct match was identified in *'Manufacture of basic iron and steel and of ferro-alloys and first products thereof'*. No modifications were implemented.
		Non-ferrous metal	This product category was modelled as an aggregation of two sectors in Exiobase, comprising *'Aluminium production'* (70%) and *'Copper production'* (30%).
	Hardware	Metal tools and hardware	A direct match was identified in 'Manufacture of fabricated metal products, except machinery and equipment'. No modifications were implemented.
		Outdoor tools and machinery incl. powered outdoor tools and lawnmowers	A direct match was identified in *'Manufacture of machinery and equipment n.e.c.'*. No modifications were implemented.
	Other	Other (n.e.c.)	To reflect the range of possible products, this was modelled as aggregation of all Tier 3 products found under the *Other* Tier 1 category as follow: ▸ Wood and timber products (56%) ▸ Plastic products (6%) ▸ Rubber products (3%) ▸ Ferrous metal (22%) ▸ Non-ferrous metal (3%) ▸ Metal tools and hardware (6%) ▸ Outdoor tools and machinery (6%) This was used as a high-level model representing the breath of products found under this 'Other' category.

3 Results

3.1 Emission factors list

The final list of emission factors developed during this analysis is reported in Table 3 below.

Table 3 Finalised emission factors list

Tier 1	Tier 2	Tier 3	GHG emissions *CO_2-eq / kg of product*	Water *litre / kg of product*	Land *m^2 / kg of product*
Clothing and textiles	Clothing	Clothing (knitwear)	38	1,039	263
		Clothing (other than knitwear)	29	1,590	44
		Clothing (n.e.c.)	30	1,515	74
	Footwear	Footwear	12	540	57
	Textiles	Raw textiles and fabrics	16	1,456	66
		Textile products and carpet	20	1,442	82
		Handbags and suitcases	17	700	106
		Textile (n.e.c.)	19	1,352	85
Toys, games, household & homewares	Furniture	Indoor furniture	6	167	102
		Cushions and furnishings	34	1,316	141
	Homewares, Bric-a-brac, electronics	Glassware	1	13	0
		Ceramics and pottery	1	48	1
		Metal homewares, cutlery and cookware	8	178	8
		Toys, sports, games, art supplies and bric a brac	5	175	64
		Books, magazines, software and video games	29	1,086	254
		Music and videos	8	287	32
		Computers, peripherals and home electronics	143	3,596	127
		Whitegoods and large appliances	10	295	9
		Homewares, bric-a-brac and electronics (n.e.c.)	10	315	93
Other	Building materials	Wood and timber products	1	44	176
		Plastic products	6	198	8
		Rubber products	4	152	11
		Ferrous metal	4	69	1
		Non-ferrous metal	9	141	7
	Hardware	Metal tools and hardware	8	178	8
		Outdoor tools and machinery incl. powered outdoor tools and lawnmowers	10	295	9
	Other	Other (n.e.c.)	3	85	100

3.2 Analysis of drivers

A high-level analysis of the main contributors to the different product categories was conducted at the sub-category level. The results are discussed in Table 4 below.

Table 4 Analysing drivers of impacts for Tier 2 product category level.

Tier 2	GHG emissions	Water	Land
Clothing	In the case of knitwear, emissions are driven by wool production, represent close to 30% of total emissions. When wool is excluded, emissions of fibre production represent approximately 10% of the emissions.	In case of knitwear, water consumption of wool production represents approximately 25% of the total, while it represents over 50% in the case of non-knitwear products. Wool water use is lower than plant-based fibres, because plant-based fibres such as cotton require irrigation. In addition, water requirements of animal rearing are allocated between meat and wool production.	In terms of land use, wool production and plant-base fibres are the two main drivers, representing over 80% of the total.
Footwear	Even though it is a relatively small fraction of the total, the leather inputs drive emissions with 46% of the total, followed by plastic with 33%.	Water use is relatively equally distributed between leather (34%), textile (38%) and plastic (27%).	Leather production represents approximately 2/3 of land occupation.
Textiles	In the case of suitcase and handbags, the production of leather is the main driver of emissions (>70%). In the case of other textile products, the production of fibres and the manufacturing process itself drives the impacts in a similar fashion to clothing products.	Similarly to the GHG emission results, the production of leather is the most significant contributor to water consumption, representing over 60% of the total. Other textile products will have comparable outcomes as clothing products (other than knitwear).	Again, leather production represents the most significant driver here with 85% of land occupation for handbags and suitcases. Other textile products will have comparable outcomes as clothing products (other than knitwear).
Furniture	Impacts of indoor furniture are driven by material inputs, including metal (33%), wood (12%), plastic (4% and glass (5%). Other manufacturing inputs represent 36% of emissions. Impacts distribution of cushions and furnishing is closely aligned with clothing products.	For indoor furniture, A similar distribution was identified for water, with material driving consumptions, including metal (27%), wood (13%), plastic (5%) and glass (4%). Other manufacturing inputs represent 43% of total water consumption. Impacts distribution of cushions and furnishing is closely aligned with clothing products.	Land occupation of indoor furniture is driven by wood inputs to the sector, representing close to 90% of the total. Impacts distribution of cushions and furnishing is closely aligned with clothing products.
Homewares, bric-a-brac, electronics	Impact distributions vary widely in the category, as products represented also vary significantly from relatively simple product (glassware, ceramics) to complex products such as computers and televisions. Generally speaking, emissions are distributed between raw material inputs, manufacturing and other parts of the supply chain. For instance, in the case of computers, peripherals and home electronics, manufacturing represents a significant part of the emissions (~30%), with raw materials such as metals representing the second largest source of emissions (>20%). In the case of single material products such as glassware or ceramics, manufacturing becomes even more significant, representing with energy	The outcome here is similar to the GHG emissions results, with varying results depending on the typology of products. Generally speaking, however, water consumption is most closely associated with raw material production upstream than with product manufacturing. This is for instance the case with computer peripherals and home electronics, where water consumption is largely associated with materials (~40%).	Land occupation of the different product category vary widely. One significant driver is the proportion of biomaterial in the product such as wood and paper. Products including books, magazines and toys (which include wooden toys), will have a significantly larger land occupation footprint associated with forestry needs, compared to products such as glassware which are produced from comparatively more concentrated mines and manufacturing sites. The only exception to this is the computer, peripherals and home electronics category, for which land use is relatively high. This may be explained

Tier 2	GHG emissions	Water	Land
	related emissions representing 30-40% of the total.		by the sheer complexity of the associated supply chain, and the material extractions needs of the electronics sector.
Building materials	In all cases, the manufacturing of raw material drives the impacts here, with varied proportions (rubber & plastic: 40-60%, ferrous and non-ferrous metal: >80%, wood ~ 40%)	Water use is variable amongst the five supply chains being represented. In the case of plastic and rubber products, raw material production represents about two thirds of the water consumption. Non-ferrous metals are driven by energy consumption, particularly electricity which represent 50% of the water consumed. In the case of ferrous metal, the manufacturing process itself is the most significant driver, represent ~30% of water consumption.	Land use is low for most product category except wood. This can clearly be explained by the varied needs of the timber supply chain compared to the production of metals and petrochemical products. In the case of wood product, forestry represents the most significant factor with over 90% of total land use.
Hardware	Raw materials are the main driver of impacts, particularly basic metal (ferrous and non-ferrous). Other aspects are marginal.	In line with the GHG emissions results, basic metal manufacturing is driving the results.	Impacts on land use are distributed across the supply chain, with basic metal production representing approximately half of the land use.

4 Conclusions

This analysis successfully developed a representation of all product categories considered by CRA under their reuse calculator within a single data source. This aligns the information represented by the emission factors to a single modelling approach.

Using a multi-regional input-output model such as Exiobase is particularly useful as it allows to trace global supply chains and their effects. Given Australia's reliance on imports for consumer goods, this type of modelling approach is particularly suitable.

However, the quality and representativeness of the data is constrained by the level of breakdown available in the existing models, and the extent to which it can be appropriately tailored to represent different supply chains.

In this case, a number of assumptions had to be made, either because the product category was generic, which did not allow to find clear representations in the available list, or because it was too specific, and a single sector could represent several product groups. In each case, we attempted to tailor the model as best as possible to allow a meaningful differentiation of each product group.

Nevertheless, these emission factors still carry significant levels of uncertainty and should be used with care. Our recommendation would be to limit the use of these factors to high-level calculations, with results grouped at the Tier 1 or Tier 2 level, rather than at the Tier 3 level. These factors would be particularly suitable for annual reporting, for instance by charity groups.

Despite these limitations, we believe that this list is a step in the right direction, providing data from a unique and well recognised source. It will allow for regular updates and improvements, with future updates of the Exiobase database, continuously improving the emission factors used by CRA as a result.

5 References

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