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Updates to Australia's e-stewardship model

TECHNICAL REPORT

Commonwealth Department of Agriculture, Water and the Environment

20 May 2022

Citation

Bontinck PA and Bricout J (2022) Updates to Australia's e-stewardship model. A report prepared for the Commonwealth Department of Agriculture, Water and the Environment by Iceni Group and Lifecycles, Sydney, Australia.

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1 Introduction

In 2021, the Department of Agriculture, Water and the Environment ('the Department') commissioned Iceni and Lifecycles to develop a quantitative foundation to help inform future policy development for e-waste. A detailed stock and flow model of the consumption of e-products in the Australian economy was developed to project future amounts of different types of e-wastes to 2030, and explore the impact of different of different management scenarios.

During the stakeholder engagement conducted by the Department that followed the publication of the study (Bontinck et al. 2021) and associated model, potential short term improvements to the model were highlighted. These ranged from aspects of the classification of certain commodities, to comments on the approach taken to model specific components such as printed circuit boards.

Iceni and Lifecycles were subsequently commissioned to undertake a further review of the model, engaging with relevant industry and international stakeholders. A short summary of the stakeholder engagement process is reported in Section 2. Based on the outcomes of these discussions and further research, the updates to the model described in Section 3 were implemented.

The updates include:

- adjusting the classification of certain e-products in the model by remapping of Harmonized System (HS) codes against UNU codes
- determining proportion of electrical and electronic products in 'mixed' product codes (mowers and toys)
- correcting material fraction data entry
- refining the approach used to represent material breakdowns in printed circuit boards
- identifying source of differences with Victorian modelling – and whether this should impact the national model.

An overall analysis of the effects associated with these modifications is provided in Section 4.

2 Stakeholder engagement

Many stakeholders provided invaluable feedback to the model during the Department's engagement processes.

We thank the following organisations and individuals for their input into this update:

- Kees Baldé, Senior Scientific Specialist at United Nations Institute for Training and Research (UNITAR) for reviewing specific assumptions against the UNITAR international method. In particular, adjustments to product classifications and best practice approaches for modelling material flows of photovoltaic systems.
- Sonya Rand, Head of Sustainability at Bunnings for providing information on the fraction of electric and fuel powered lawn mowers sold on average. This was used to differentiate electric lawn mowers from fuel powered lawn mowers in the model. This is significant as fuel powered lawn mowers do not fall under the definition of e-products.
- Chris Foley, Head of Energy and Environment, and Thomas Hamblin, Climate and Environment Advisor, at Kmart and Target Australia for providing detailed sales data for analysis by Lifecycles to assess the proportion of product toys sold which would be defined as e-products for the purpose of this model.
- Alice Sanderson, Executive Manager at National Toys Association, and Nick Harford, Managing Director at Equilibrium, for sharing information on the proportion of toys which can be defined as e-products as found in the material flow analysis for toys currently underway, supported by Sustainability Victoria.
- David Crossley, National Technical Manager, and David Oxley, Environment & Public Affairs Officer, at Lighting Council Australia for explaining the varying nature of lifespan for different lighting products, and implications of phasing out of certain types of products and the shift towards LED.
- Greg Picker, Executive Director at Refrigerants Australia, and Gary Knox, Engineering Manager at Daikin Australia, for identifying data entry errors in some material fractions and suggesting further research into different types of printed circuit boards.
- Sustainability Victoria and Paul Randell, Director at Randell Environmental Consulting, for sharing their Solar Photovoltaic (PV) Systems model and report to analyse differences in approaches.

3 Summary of updates

3.1 Classification updates

The e-stewardship model relies on three levels of product categorisation. The Harmonized System (HS) of trade codes are the most disaggregated level. These codes are used by the Australian Border Force to record imports into and exports from Australia. The global flow of commodities is represented by thousands of trade codes, with e-products represented by a subset of several hundred codes.

The United Nations University mapped these HS trade codes against 54 product categories in the E-waste Statistics Guidelines (UNU-Keys). These 54 categories share comparable average weights, material compositions, end-of-life characteristics, lifetime distributions and functions, and were used as the basis of the e-stewardship model.

To assist readability and reporting of information, these UNU Keys were further aggregated into eight broad categories of e-products, which formed the basis of analysis for the report.

After consultation with stakeholders including the United Nations University (now United Nations Institute for Training and Research – UNITAR), the ten categories in Table 1 were reclassified.

Table 1 – Classification updates in version 1.1

Category	V1 Classification	V1.1 Classification
UNU-Key 0307 Professional IT Equipment	TV and computing equipment	Other large equipment
HS 846729 Tools; for working in the hand, with self-contained electric motor; other than saws and drills	UNU-Key 0601 Household tool	UNU Key 0602 Professional tool
HS 851511 Brazing or soldering machines and apparatus; soldering irons and guns, whether or not capable of cutting	UNU-Key 0601 Household tool	UNU Key 0602 Professional tool
HS 851519 Brazing or soldering machines and apparatus; other than soldering irons and guns, whether or not capable of cutting	UNU-Key 0601 Household tool	UNU Key 0602 Professional tool
HS 851521 Welding machines and apparatus; for resistance welding of metal, fully or partly automatic, whether or not capable of cutting	UNU-Key 0601 Household tool	UNU Key 0602 Professional tool
HS 851529 Welding machines and apparatus; for resistance welding of metal, other than fully or partly automatic, whether or not capable of cutting	UNU-Key 0601 Household tool	UNU Key 0602 Professional tool
HS 851531 Welding machines and apparatus; for arc (including plasma arc) welding of metals, fully or partly automatic, whether or not capable of cutting	UNU-Key 0601 Household tool	UNU Key 0602 Professional tool
HS 843311 Mowers; lawn, parks or sports-grounds, powered, with the cutting device rotating in a horizontal plane	UNU-Key 0602 Professional tool	UNU Key 0601 Household tool
HS 843319 Mowers; for lawns, parks or sports-grounds, other than with the cutting device rotating in a horizontal plane	UNU-Key 0602 Professional tool	UNU Key 0601 Household tool
HS 851610 Heaters; electric, instantaneous or storage water and immersion heaters	UNU-Key 0203 Small household equipment for hot water preparation	UNU-Key 0106 Household heating & ventilation

3.2 E-product portions in 'mixed' categories

Even at the most disaggregated level, product classifications for international trade accounting sometimes mix e-products with other types of products. Toys and household tools were identified as two categories worthy of further distinction.

Following further research and consultation with industry, the changes outlined in Table 2 were implemented in the e-stewardship model.

Table 2 – Portions of e-products assigned to 'mixed' categories

Product category	Estimated fraction of e-product (mass)	Justification
UNU Key 0701 Toys		
HS 950490 Games; articles for funfair, table or parlour games, including pintables, special tables for casino games, automatic bowling alley equipment, n.e.c. in heading 9504	26% Assumed to be constant over time.	Estimate based on detailed trade flows sourced from the Australian Government Department of Foreign Affairs and Trade (2022), differentiating products likely to be classified as e-products from others. Note that these data are strictly in financial terms and an alternative estimate that uses the mass of products could modify the results.
HS 950300 Tricycles, scooters, pedal cars and similar wheeled toys; dolls' carriages; dolls; other toys; reduced-size (scale) models and similar recreational models, working or not; puzzles of all kinds	8% Assumed to be constant over time.	Information communicated by Equilibrium (Harford 2022). This was correlated with sales data shared in confidence by Kmart (Kmart 2022), which estimated 12% of the value of this category of products sold could be classified as e-products.
UNU-Key 0601 – Household tools		
HS 843311 Mowers; lawn, parks or sports-grounds, powered, with the cutting device rotating in a horizontal plane	60% Linear growth from 1990, assuming 2% of mowers were electric by then. Forecasted consumption assumed to increase linearly alongside other products in the same UNU-Key.	Estimation communicated by a representative for Bunnings places the split of electric and fuel mowers at 60% electric and 40% petrol.
HS 843319 Mowers; for lawns, parks or sports-grounds, other than with the cutting device rotating in a horizontal plane		

3.3 Material fraction data

Minor data entry errors in the material fraction breakdowns for the following categories were identified and corrected:

- UNU 0102 – Dishwashers
- UNU 0103 – Kitchen equipment
- UNU 0104 – Washing machines
- UNU 0108 – Fridges
- UNU 0109 – Freezers
- UNU 0111 – Air conditioners
- UNU 0114 – Microwaves
- UNU 0201 – Other small household equipment
- UNU 0202 – Equipment for food preparation
- UNU 0203 – Small household equipment for hot water preparation
- UNU 0204 – Vacuum cleaners
- UNU 0205 – Personal care equipment
- UNU 0407 – Cathode ray tube TVs
- UNU 0408 – Flat display panel TVs

For product categories that are not well characterised in the literature, the model uses material fractions from similar categories. These corrections therefore also influenced other product categories, as summarised in Table 3 below.

Table 3 – Indirect material fraction updates

Category modified indirectly	Reason for modification
UNU 0001 – Central heating UNU 1002 – Cooled dispensers	Modelled as an average of other 'Temperature exchange equipment' products. Indirectly affected by corrections made to UNU 0108 (Fridges), UNU 0109 (Freezers) and UNU 0111 (Air conditioners), which form parts of this average.
UNU 0113 – Professional cooling equipment	Modelled as equivalent to UNU 0111 (Air conditioners), which has been corrected.
UNU 0305 – Telecommunication equipment UNU 0401 – Small consumer electronics UNU 0402 – Portable audio & video UNU 0403 – Music instruments, radio, HiFi UNU 0404 – Video UNU 0405 – Speakers UNU 0406 – Cameras UNU 0501 – Lamps UNU 0504 – Special lamps UNU 0506 – Household luminaires UNU 0507 – Professional luminaires UNU 0601 – Household tools UNU 0701 – Toys UNU 0702 – Game consoles UNU 0801 – Household medical UNU 0901 – Household monitoring & control	Modelled as average of 'Other small equipment' products. Indirectly affected by corrections made to UNU 0114 (Microwaves), UNU 0201 (Other small household equipment), UNU 0202 (Equipment for food preparation), UNU 0203 (Small household equipment for hot water preparation), UNU 0203 (Vacuum cleaners) and UNU 0205 (Personal care equipment), which form part of this average.
UNU 0602 – Professional tools UNU 0703 – Leisure UNU 0802 – Professional medical UNU 0902 – Professional monitoring & control UNU 1001 – Non-cooled dispensers	Modelled as an average of 'Large household applications' products there are data for. Indirectly affected by corrections made to UNU 0102 (Dishwashers), UNU 0103 (Kitchen equipment) and UNU 0104 (Washing machines), which form part of this average.

3.4 Printed circuit board material fractions

In the original e-stewardship model, printed circuit boards were considered to be the same across all e-products. While this was a useful proxy to develop a baseline, not all circuitry is created equally. For example, complex products such as mobile phones or computers require complex circuit boards in comparison to a fridge or air conditioning unit. While the weight of materials in PCBs is incredibly minor, their monetary value – particularly for precious metals – significantly influences the overall value of the e-waste.

A study on the metal content of printed circuit boards for 21 types of e-waste by Oguchi et al. (2011) was used to further detail material fractions for printed circuit boards in different types of e-products. The product categories considered by Oguchi et al. (2011) were mapped against the list of UNU-Keys, as shown in Table 4. While this mapping was not always direct, for example lamps are obviously very different from washing machines, it enabled the model to differentiate between products which are expected to have high performance circuitry compared with products requiring lower outputs.

Table 4 – Product mapping for printed circuit board data

Product categories in Oguchi et al. (2011)	UNU-Keys the data was mapped to	
Refrigerator	UNU 0108 – Fridges	UNU 0109 - Freezers
Washing machine	UNU 0102 – Dishwashers UNU 0103 – Kitchen equipment UNU 0104 – Washing machines UNU 0105 – Dryers UNU 0114 – Microwaves UNU 0201 – Other small household equipment UNU 0202 – Equipment for food preparation UNU 0203 – Small household equipment for hot water preparation	UNU 0204 – Vacuum cleaners UNU 0205 – Personal care equipment UNU 0501 – Lamps UNU 0602 – Professional tools UNU 0703 – Leisure UNU 0802 – Professional medical UNU 0902 – Professional monitoring & control UNU 1001 – Non-cooled dispensers
Air conditioner	UNU 0001 – Central heating UNU 0101 – Professional heating & ventilation UNU 0106 – Household heating & ventilation	UNU 0111 – Air conditioners UNU 0113 – Professional cooling equipment UNU 1002 – Cooled dispensers
DVD player/recorder	UNU 0404 – Video	
Stereo system	UNU 0402 – Portable audio & video	UNU 0403 – Music instrument, radio, HiFi
Telephone	UNU 0305 – Telecommunication equipment	
Digital camera	UNU 0406 – Cameras	
Portable MD player	UNU 0401 – Small consumer electronics	
Video game	UNU 0702 – Game consoles	
CRT TV, Plasma Display Panels, LCD TV, Desktop PC, Notebook PC, Printer, Mobile phone	Not used – specific PCB material breakdown was considered in the original data.	
VCR, Radio cassette recorder, Facsimile	Not used – obsolete	
Camcorder, Portable CD player	Not used – included in other categories	

3.5 Photovoltaic modelling

Two approaches can be applied to model the quantity of solar PV and battery storage flowing through the Australian economy:

- using trade statistics and existing trade codes to represent the volume of products consumed over time – as is the case for other product categories in the e-stewardship model
- using geographically-specific installation data, that differentiate between different scales of installation (from household rooftop solar systems to large-scale solar farms). This is the approach used in the e-stewardship model for solar PV and battery storage.

Recently, differering approaches have been used to develop a number of models that represent the flow of e-products and e-waste at the state level. While models developed for Queensland and South Australia use the same approach as our model, the model developed for Victoria uses international trade statistics for this product category.

As part of the model update, we held a meeting with scientists from UNITAR to review some key assumptions of the model, including our approach to model solar PV and battery storage products (Baldé 2022). UNITAR is responsible for the development of the Global E-Waste Monitor model (Forti et al. 2020), as well as the e-waste statistics guidelines (Forti et al. 2018), and as such has invaluable resources and experience in the modelling of e-product and e-waste flows.

The discussion highlighted that using trade codes was not recommended for this specific product category, as the existing codes are too generic and do not accurately represent these products. Actual installation statistics were deemed to be a more reliable source of information to estimate the mass flow of photovoltaic products.

This feedback confirmed our original approach. Highlighting the existence of these two options is important, as it goes a long way in explaining variations in results between states.

In addition, a detailed review of UNU-Key 0002 (Photovoltaic panels) highlighted two minor errors in the model. The first was an inconsistency in the estimated mass of inverters used in PV systems, which resulted in a slightly overestimated weight of material. The second had to do with the material fraction data used to represent solar panels in the model, which was corrected to represent solar panels, inverters and mounting systems, as was originally intended.

4 Effects of updates on the results

This section discusses the impacts of updating the model to version 1.1 on the model's key results.

4.1 Overall mass

Mild variations in the quantities of e-products entering the economy and leaving as e-waste are observed, as outlined in Table 5 using 2019 as a reference year.

In 2019, the total mass of e-products entering the market was estimated as 940,000 tonnes, 4% lower than the original model, while e-waste was estimated as 511,000 tonnes, 2% lower than previously estimated. The amount of waste was affected by the estimate of the fractions of e-products in 'mixed categories' (mowers and toys), and some minor corrections to the solar PV and battery storage model (see Section 3.5).

Other variations in between categories are due to the reassignment of specific trade codes to different UNU-Key categories (Table 1). We note here that the sum of all percentage variations does not add up to the total percentage variation because several products categories were shifted from one category to another, as explained in Section 3.1.

Table 5 – Variation in e-product flows resulting from model updates (tonnes, 2019)

	E-products			E-waste		
	V1	V1.1	% variation	V1	V1.1	% variation
Solar PV and battery storage	333,460	302,580	-9%	3,400	3,120	-8%
TV and computing equipment	84,940	84,940	0%	113,020	111,730	-1%
Mobile phones	4,400	4,400	0%	3,670	3,670	0%
Lighting equipment	43,770	43,770	0%	47,390	47,390	0%
Large household appliances	141,350	143,670	2%	71,990	73,060	1%
Temperature exchange equipment	218,330	220,420	1%	122,770	122,290	0%
Other small equipment	124,730	120,670	-3%	141,550	135,980	-4%
Other large equipment	23,770	19,140	-19%	16,790	13,640	-19%
TOTAL	**974,750**	**939,600**	**-4%**	**520,600**	**510,900**	**-2%**

Note: sum of rows may not equal to total due to rounding.

4.2 Material fractions

One of the more significant updates to the model relates to the material fraction estimates.

Firstly, the adjustment of material fraction breakdowns due to minor data entry errors resulted in increasing the fraction of plastics and non-ferrous metals in the waste stream. Secondly, the work done to refine the modelling of printed circuit boards had a significant effect on the estimated fraction of precious and specialty metals found in e-waste. This is apparent in Table 6, which shows the overall variation in material fraction between the two versions of the model.

Table 6 – Variation in overall material distribution resulting from update (2019)

	Plastic (%)	Glass (%)	Metal (%)	Other (%)	Metal detail			
					Ferrous	Non-ferrous	Precious	Specialty
V1	9%	2.9%	40%	9.3%	35%	4.5%	0.0015%	0.047%
V1.1	15%	3.2%	37%	7.4%	30%	6.9%	0.0009%	0.033%
% variation	**68.2%**	**10.0%**	**-5.4%**	**-20.4%**	**-13.0%**	**54.5%**	**-35.8%**	**-29.0%**

Refining the printed circuit board model affected the estimated quantities of precious and specialty metals found in e-products. This had a substantial effect on the estimate of the monetary value of materials within e-products, as reported in Table 7. It resulted in a general decrease of the overall value of material by close to 20%, with the most affected product categories being the large household appliances and other large equipment. As reported in Table 4, the value of printed circuit board materials in TV and computing equipment were not modified. The large variation in this product category are due to the correction in the overall material fractions described in Section 3.3.

Table 7 – Variation in the value of material found in e-waste (million AUD, 2019)

	V1	V1.1	% variation
Solar PV and battery storage	5	5	13%
TV and computing equipment	133	65	-51%
Mobile phones	25	25	0%
Lighting equipment	90	100	12%
Large household appliances	78	43	-45%
Temperature exchange equipment	223	210	-6%
Other small equipment	250	215	-14%
Other large equipment	21	9	-58%
TOTAL	**824**	**672**	**-18%**

5 Conclusions

The stock and flow model developed for the Department of Agriculture, Water and the Environment was built to be iteratively improved over time. As such, one aim of the model was to ensure it was easy to update certain aspects, add information and review the data.

Thanks to strong industry engagement, a number of important improvements to the model were identified that could be easily implemented.

The figures resulting from these updates are now more representative of the Australian situation.

This first iteration – Version 1.1 – maintains the Australian e-stewardship model as a sound foundation for future policy developments.

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