TSA Driving sustainable outcomes for end-of-life tyres

TyreStewardship AUSTRALIA

Life Cycle Assessment of Agriculture and Mining Off-the-Road (OTR) Tyres

A comparison of recovery scenarios for agriculture and mining OTR tyres

Australian Government Accredited Product Stewardship Scheme

Life Cycle Assessment of Agriculture and Mining Off-the-Road (OTR) Tyres

Version 1.0

August 2024

Project delivered for
Tyre Stewardship Australia (TSA)

Project information delivered by
Edge Impact

Note
Information contained in this report has been adapted from original report delivered by Edge Impact. Whilst the information is consistent, there have been some changes/adaptions from the original.

Disclaimer

This report is made available by Tyre Stewardship Australia Ltd (ACN 164 971 939) (**TSA**).

By viewing, reading or otherwise using this Report you understand, acknowledge and agree that:

- this Report and the information, calculations, data and case studies included in this Report (**Report Information**):
  - is provided for general information purposes only
  - does not take into account any or all of the specific circumstances relevant to you or any other person
  - does not constitute a recommendation by TSA or any other person, and
  - does not constitute any legal, financial or investment advice and is not to be relied upon as, nor to be used as a substitute for, legal, financial or investment advice.
- TSA provides no guarantee that the Report or any Report Information is accurate, current or complete
- to the extent permitted by law, TSA accepts no responsibility or liability for any loss which may be suffered or incurred by any person who acts, or refrains from acting, on or as a result of this Report or any Report Information, and
- unless stated otherwise, copyright in this Report is owned by TSA and no part of this Report may be reproduced or used for commercial purposes without the prior written consent of TSA.

Acknowledgement

Tyre Stewardship Australia acknowledges the Traditional Custodians of the land and waterways on which we live, work, and depend. We acknowledge the unique spiritual and cultural connection, and continuing aspiration that the Traditional Owners have for Country, and we pay respect to Elders, past, present, and emerging.

Contents

Acronyms

Acronym	Description
EOL	End-of-Life
OTR	Off-the-Road
TSA	Tyre Stewardship Australia
LCA	Life Cycle Assessment
TDP	Tyre-Derived Product
ISO	International Standards Organisation
GWP	Global Warming Potential
CTU	Comparative Toxic Units
MJ	Megajoules
GHG	Greenhouse Gas
LCIA	Life Cycle Impact Assessment
IPCC	Intergovernmental Panel on Climate Change
AusLCI	Australian Life Cycle Inventory
ALCAS	Australian Life Cycle Assessment Society
DCCEEW	Department of Climate Change, Energy, the Environment and Water

Glossary

Biogenic
Anything produced by or made of living organisms.

Crumb
A refined rubber product, typically less than 1 mm in diameter, made from recycled tyres.

Disposal
The dumping, landfilling, direct incineration, unsustainable burning, and stockpiling as an end point of used tyres.

End market
The end destination for a product, in this case a tyre-derived product

End-of-life tyre
A tyre that is deemed no longer capable of performing the function for which it was originally made.

Environmental Impact Categories
An impact category groups different emissions into one effect on the environment. By converting those emissions into one unit, this translates into one impact category.

Fossil-based/Fossil-derived
Materials formed from hydrocarbon compounds created from the remains of plant and animal life in Earth's geological past.

Granule
A refined rubber product, typically 2 mm – 15 mm, made from recycled tyres.

In-use
Tyres that are being used for the purpose for which they were originally made.

Life cycle assessment
A methodology for quantifying the environmental impacts of a product or service over the course of its entire life.

Onsite Disposal
The burial of OTR tyres and conveyor belts in mining pits, which at the time of this report was permitted by regulators throughout Australia.

Recovery
Used tyres that are collected and either reused, recycled or repurposed either in Australia, or overseas.

Shred
A processed rubber product, less than 150 mm (typically 50-80 mm), made from EOL tyres.

Tyre-derived product (also Tyre-derived material)
Any product produced from rubber, steel, textile or other material recovered from recycling EOL tyres.

Tyre recycler/processor
A business that conducts tyre processing, recovering rubber, steel, textile and/or other materials and processing it into a form whereby it can be used as an intermediate product in the manufacture of a product, or to recover as energy.

Tyre Stewardship Australia
The entity created to administer The Tyre Product Stewardship Scheme.

Tyre collector
An individual or business that collects and/or transports used tyres in any part of Australia. This includes transporters, balers, local waste facility, auto parts recyclers.

Executive Summary

Overview

End-of-life (EOL) off-the-road (OTR) tyres have much lower recycling and recovery rates in Australia, compared to other EOL tyres. This is due to additional barriers, such as difficulties in handling and transporting OTR tyres, lack of recovery services, and priorities of different parties involved. Furthermore, the environmental benefits from recovering OTR tyre are less researched and unclear.

In a previously commissioned report, ***Life Cycle Assessment of End-of-Life Tyres*** (TSA 2024), TSA investigated the environmental benefits of a range of tyre-derived products (TDPs) manufactured from passenger and truck tyres. However, as the recovery of OTR tyres has different handling and logistics requirements than passenger and truck tyres, the results from this study cannot be directly applied to the recovery of OTR tyres. EOL OTR tyres from mining and agriculture also tend to be further away from tyre recycling facilities than passenger and truck tyres.

This study looks at different recovery pathways of OTR tyres through the lens of a Life Cycle Assessment (LCA) to determine the differences in environmental impacts and to see how the results compare with the previous report on passenger and truck tyres. Figure 1 shows a proposed LCA for an end-of-life tyre, considering the impacts from the collection of the tyre, processing to TDPs and subsequent end-markets, use and end-of-life. The data in this research report considers the unique aspects of the collection and processing stages, specifically for OTR tyres.

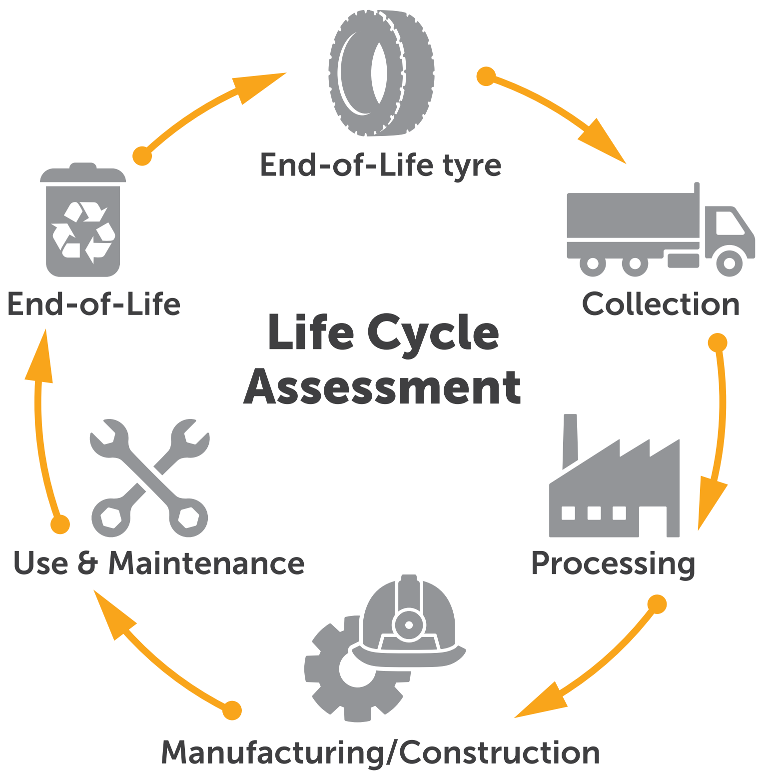


Figure 1: Life cycle assessment stages for an end-of-life tyre

Goal

The goal of this study is to quantify the global warming potential (GWP) and wider environmental impacts for five recovery scenarios for EOL OTR tyres. Specifically this will involve modelling the impacts for processing either agriculture and mining tyres into tyre-derived products (rubber shreds, granules, and crumb rubber). It also aims to investigate the potential benefits from different recovery pathways of OTR tyres and help identify solutions for improving recovery rates.

Scope

- Identify the characteristics, processing options and latest information regarding OTR tyre recovery in Australia.
- Confirm 5 scenarios to be modelled, focusing on EOL OTR tyres. Two scenarios will be for agriculture tyres and three scenarios for mining tyres.
- Conduct a LCA on scenarios, allowing for the adaptability of transport distance and truck types.

Appendix 1 includes a preliminary scoping assessment, to inform the research, which was also used in the TSA National OTR Business Case ***Tipping the balance*** (TSA 2023). This preliminary assessment involved a case study that considered the GHG emissions associated with the transport and processing of an agriculture tyre for use in an asphalt road.

Methodology

The data presented in this report was collected, modelled and assessed by ***Edge Impact***. The LCA method has been applied to the evaluation of environmental impact for this project, developed to comply with ISO 14040:2006 and ISO 14044:2006+A1:2018 which describe the principles, framework, requirements, and provides guidelines for LCA (ISO, 2006; ISO, 2018).

The LCA has been conducted using primary data from industrial stakeholders and justified assumptions, in compliance with ISO 14040/14044 methodologies. However, the report has not undergone independent third-party verification. Therefore, the LCA findings should be interpreted with caution as they be improved following an independent third-party verification.

The life cycle model was created in a leading LCA software tool, SimaPro. SimaPro is a platform that links LCA background databases with environmental impact assessment methods, making it possible to calculate impacts from an inventory model.

Figure 2 describes five scenarios, two scenarios for recovering agriculture tyres and three scenarios for recovering mining tyres, in which crumb rubber is the target TDP. The report outlines global warming potential (GWP) impacts of recovering 1 t of OTR tyre, as this is a key metric for both producers and consumers in the TDP end market. However, other environmental impacts including eutrophication – terrestrial, ecotoxicity – freshwater, water scarcity, and resource use – fossil have also been quantified and commentary provided where relevant.

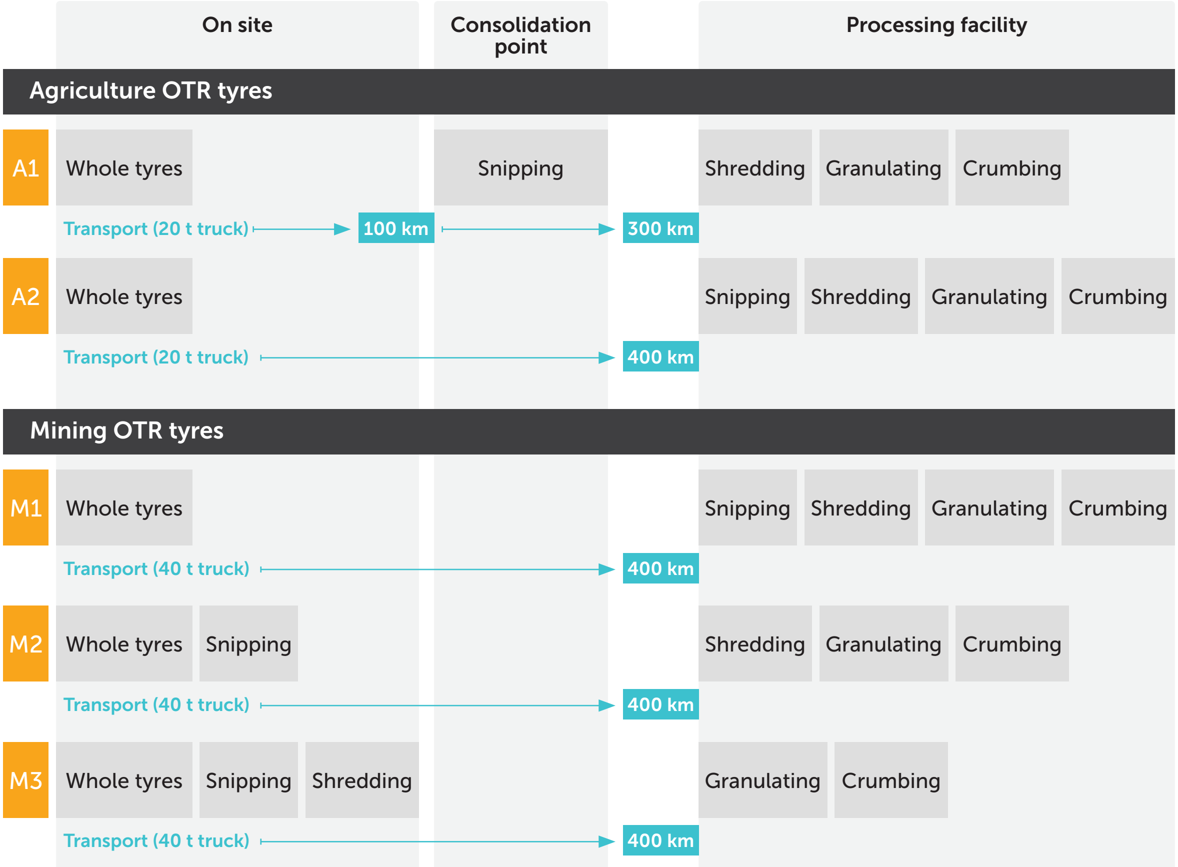


Figure 2: Scenarios modelled for agriculture and mining OTR tyres

Results

The below table presents the environmental impact of each scenario in the assessed impact categories.

	Agriculture OTR tyres		Mining OTR tyres		
	Scenario A1	Scenario A2	Scenario M3	Scenario M4	Scenario M5
GWP-T (kg CO_2 eq.)	397.09	446.89	388.08	361.33	357.89
Eutrophication, terrestrial (mol N eq.)	2081.46	2273.96	2049.10	1765.87	1752.34
Ecotoxicity, freshwater (CTUe)	2,081.46	2273.96	2049.10	1765.87	1752.34
Water scarcity (m^3 eq.)	57.29	61.60	56.53	53.36	53.06
Resource use – fossil (MJ)	2407.64	3077.57	2288.46	2046.04	1999.53

Findings

Based on the results of agriculture and mining tyre recovery scenarios and sensitivity analysis in this study, the main findings are:

1. For agriculture OTR tyres, Scenario A1 had the lowest impacts across all environmental impact categories, with a GWP of 397.09 kg CO_2 eq. for recycling 1 t of tyres.
2. For mining OTR tyres, Scenario M3 had the lowest impacts across all environmental impact categories, with a GWP of 357.89 kg CO_2 eq. for recycling 1 t of tyres.
3. For recovering 1 t of either OTR tyre, around 0.737 t of crumb rubber is produced as the end market product, with 0.263 t of steel scrap for recycling and 0.074 kg of textile fibres for disposal. This is subject to the material compositions of OTR tyre.
4. Crumbing leads to 19% to 69% of total environmental impact assessed, and snipping is the highest contributor to terrestrial eutrophication (36% to 46%), led by diesel used. Transport related activities contributes to 3% to 44% of environmental impacts in all scenarios.
5. Setting up consolidation points helps reduce the overall impact of up to 22%, which is evident from sensitivity analysis of agricultural OTR tyre.
6. The primary impediment to the capacity and efficiency of transport in the case of OTR tyre is their bulk nature. This characteristic restricts the weight that can be loaded compared to standard loads. Nevertheless, it is noteworthy that the implementation of reverse logistics mitigates the environmental impact compared to the dedicated transport.
7. For mining OTR tyre, snipping on site downsizes the tyre prior to be transported, greatly increasing the efficiency of delivery services, and reduce the unit impact from transport process. In sensitivity analysis, the amount of mining OTR tyre processed by mobile machinery during each trip has a relatively minor influence on the overall environmental impact, especially when the machinery is delivered from 200 km away. However, the primary concern centers around the accessibility of machinery, as long-distance transport can introduce considerable impacts throughout the entire process
8. Shredding on site further downsizes the tyre to enable the higher amounts of OTR tyre components to be transported, and reduce the impact accordingly. However, the delivery of shredding machinery to a remote site (e.g., 800 km) may bring a significant environmental impact, and this delivery should be avoided if a long-distance transport is required.

Key outcomes

Upon all the findings, the key outcomes are interpretated as follows:

1. Establishing consolidation points proves to be beneficial in mitigating the impact of transport, and the necessity of such points is affirmed in this study. Having a consolidation point within a 100 km of radius of the site demonstrates environmental benefits in the existing scenarios for agricultural OTR tyre recovery.
2. Snipping mining OTR tyres on-site for transport demonstrates significant environmental benefits by enhancing the efficiency of bulk transport of tyres. It should be implemented when collecting and recovering mining OTR tyres. On-site shredding, while providing a modest advantage, is possibly offset by the increased distance required for transporting the shredding equipment. This largely nullifies the benefits gained by reducing the bulk nature of the tyres from snipped to shredded.

Introduction 1

Background 1.1

Mining and agriculture play a vital role in Australia and are both a larger consumer of tyres, making up almost a third of all tyres consumed in Australia annually by weight.
While mining and agriculture make up a considerable proportion of all tyres consumed by weight, the recovery of the off-the-road (OTR) tyres from these industries falls well short of other industries and society.

The barriers to recovery of OTR tyres from mining and agriculture include difficulties in handling and transporting OTR tyres, lack of recovery services, and priorities of different parties involved. As a result, the environmental benefits from recovering OTR tyres are less researched and unclear.

In a previously commissioned report, ***Life Cycle Assessment of End-of-Life Tyres*** (TSA 2024), TSA investigated the environmental benefits of a range of tyre-derived products (TDPs) manufactured from passenger and truck tyres. However, as the recovery of OTR tyres has different handling and logistics requirements than passenger and truck tyres, the results from this study cannot be directly applied to the recovery of OTR tyres. End-of-Life (EOL) OTR tyres from mining and agriculture also tend to be further away from tyre recycling facilities than passenger and truck tyres.

This study looks at different recovery pathways of OTR tyres through the lens of a life cycle assessment (LCA) to determine the differences in environmental impacts and to see how the results compare with the previous report on passenger and truck tyres.

Objectives of the Research 1.2

The overall objectives of this study are to:

- Analyse and quantify the greenhouse gas (GHG) emissions and other environmental implications of five recovery scenarios for EOL OTR tyres relating to the agriculture and mining sectors.
- Evaluate the results for EOL OTR tyre recovery pathways, including which scenarios produce the least environmental implications.

EOL Tyre Characteristics 2

Variability of OTR Tyres 2.1

OTR tyres come in a range of rim size, from a forklift tyre with a rim of less than 20 cm that could be picked up in one hand, to mining dump truck tyres with a rim size of nearly 2 m that weigh up to five tonnes. OTR tyres also vary in composition depending on tyre types and applications. Generally, rubber compounds are the main component of a tyre, but the portion of steel/fibre reinforcement varies associated with OTR tyre type. When considering recycling an OTR tyre, rubber is the predominant target to be reprocessed, while the steel/fibre reinforcement are potentially recycled during the process

OTR tyres in most cases are used in heavy-duty industries and sectors such as agriculture, aviation, construction (and demolition), defense, industrial (manufacturing and trade), and mining (TSA, 2023).

This study focuses on the recovery of agriculture and mining tyres.

The import of mining tyres is dominated by the 57 inch and 63 inch rim sizes by weight, while agriculture sector frequently uses tyres within the 42 inch (TSA, 2023). There is a tendency that the size of tyres used in the agriculture sector increases, half of which being currently used is 38 inch or larger.

Table 1 describes an indication of the range of tyre sizes and corresponding average weights for the tyre types modelled. A uniform loss rate of 16% has been provided estimated and applied for all tyre types. This wear rate is assumed to apply for all new OTR tyre components except for the metal reinforcement and fibre, as these components are not part of the tread. These figures also assume that the tread composition is representative of the whole tyre composition. The dimensions and weights of OTR tyres will have an impact on the number of tyres collected with each truck load.

Table 1: Indicative OTR tyre sizes and weights (TSA, 2023)

OTR tyre	Rim size (inches)	Average weight (kg)	Avg. weight at EOL (16% wear)
Agriculture	<15″	<30	<25
	15″ to <20″	30	25
	20″ to <24″	70	59
	24″ to <32″	100	84
	32″ to 38″	170	143
	40″	200	168
	42″	280	235
	44″	410	344
	46″	230	193
	50″	200	168
	54″	170	143
Mining	<15″	<30	<25
	15″ to <20″	35	29
	20″ to <24″	120	101
	24″ to <29″	350	294
	29″ to 35″	1000	840
	>=39″	1800	1512
	>=45″	2500	2100
	>=49″	1500	1260
	>=51″	2400	2016
	>=57″	3800	3192
	>=63″	5000	4200

OTR Tyres Collection and Processing 3

Recovery Rates and Potential Recovery Pathway 3.1

The current OTR tyre recovery rate of around 10% relates mainly to OTR tyres generated in urban settings, led by manufacturing and construction vehicles, and aviation sector. Most EOL OTR tyres coming from regional and remote locations are dominantly onsite disposed, sent to landfill, or illegally dumped. Table 2 shows an indication of agriculture and mining OTR tyres regarding their EOL fates. To align to Australian waste and circular economy strategies, industry is driving to achieve an OTR tyre recovery rate of 55 to 60% to contribute to overall 80% EOL tyre recovery by 2030 (TSA, 2023).

Table 2: EOL OTR tyres end market in 2018-19 by tyre type (TSA, 2023)

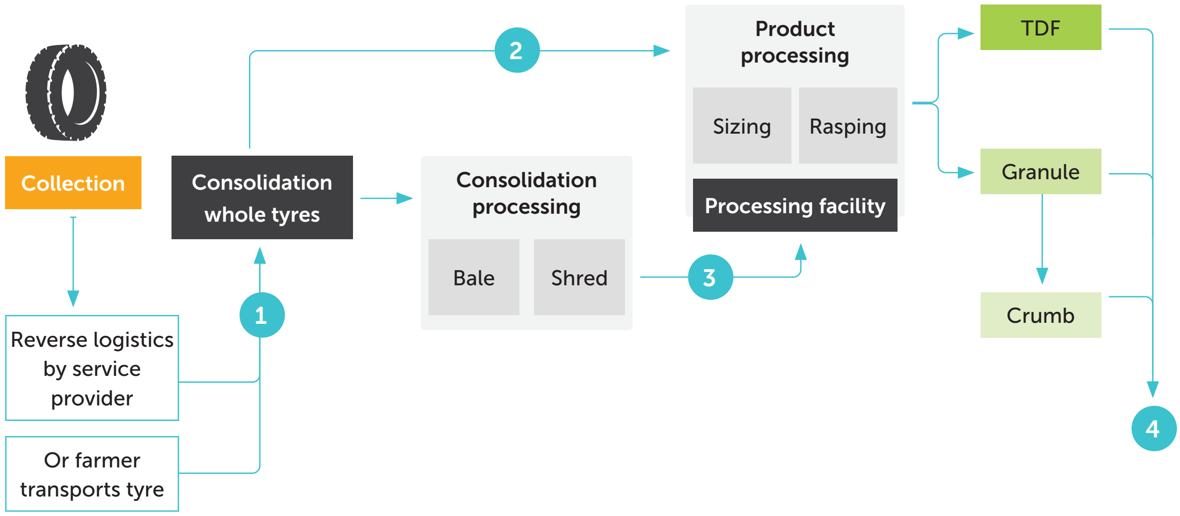
Fate	Agriculture OTR tyres	Mining OTR tyres
Civil engineering	1%	1%
Crumb, granules & buffings	-	-
Pyrolysis	-	1%
Stockpiles (>40 t, 5,000 EPU)	2%	2%
Landfill	4%	3%
Onsite disposal	90%	93%
Dumping dispersed	3%	-
Total	**100%**	**100%**

A typical tyre contains steel, textiles, and rubber. The recycling process of EOL tyres separates these components so that the steel wire scrap can be recycled into new steel, the textile (e.g. nylon) fibres can be disposed of and the rubber can be processed to the appropriate size (Rouwette, 2020). In this regard, the waste rubber is processed to TDPs available for multiple uses, such as crumb rubber for road construction, and tyre-derived fuel (TDF) for energy consumption. If the waste steel scrap is recycled and sold, it is possible for EOL tyre recyclers to gain benefits from the activities in both economic and environmental perspectives.

On the other hand, current tyre recovery facilities are normally designed for passenger car and truck tyres, and their accessibility for OTR tyres is limited. The general processes for OTR tyre recovery are firstly to consolidate and snip or coarsely shred the whole tyre, and smaller segments can be transported and further processed depending on the demands and applications. To encourage overall OTR recovery rate, the *Tipping the balance* report proposed alternate pathways to deal with larger sizes of OTR from agriculture and mining sectors, without using facilities servicing passenger car and truck tyres, as shown in Figure 3 and Figure 4.

The design of OTR tyre recovery pathway can take advantage of reverse logistics which offers a flexibility to pre-process EOL OTR tyre either on site or off site. However, the challenges regarding the efficiency of reverse logistics, handling of tyres, and necessity of pre-processing (snipping) will be investigated and addressed in this study.

Figure 3: A recovery pathway for EOL OTR tyres from the agriculture sector (TSA, 2023)



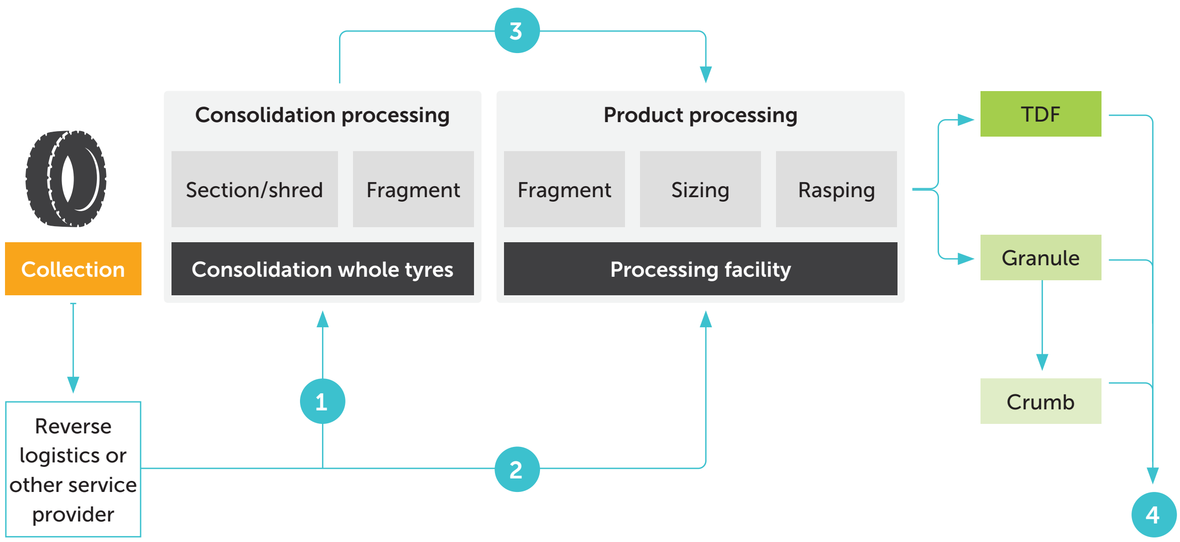
1. Collection distance from individual farms to a consolidation point is the same whether tyre service provider collects versus the farmer. Distance varies up to 200 km

2. Distance from consolidation point to product processing plant is maximum 500 kms – for transport of whole unbaled OTR tyres.

3. Consolidation point is adjacent to consolidation processing plant (if relevant), therefore distance to product processing plant is consistent (maximum 500 kms) – transport of baled or shredded OTR tyres.

4. Distance to market by product from product processing plant. Each product has assumed distance to market set.

Figure 4: A recovery pathway for EOL OTR tyres from the mining sector (TSA, 2023)



1. Distance from individual mine operation to a consolidation point (servicing multiple mines) – transportation of whole tyres.

2. Distance from individual mine operation to a product processing plant – transportation of whole tyres.

3. Distance consolidation processing plant (occurring as consolidation point) to product processing plant – transportation of sections, shred or specified fragments.

4. Distance to market by product from product processing plant. Each product has assumed distance to market set.

OTR Tyre Collection

3.2

EOL OTR tyre collection is uncommon, and the efficiency of its collection will be subjected to the truck type and shipping method (placement of tyres) if a reverse logistics method is employed. As agriculture and mining OTR tyres tend to be larger in size, the capacity of truck should be considerable. Engagement and discussion with a logistics company involved in delivering new OTR tyres determined that a 40 t truck or larger was the most appropriate for transporting mining tyres. In addition, OTR tyres with a rim size smaller than 57 inch can be laid down to maximise the efficiency of collection regarding the cargo volume. For agriculture OTR tyres, it is assumed that 20 t truck is employed for delivery service.

Table 3: Typical delivery service for the larger size of new OTR tyre

	No. of 57-inch OTR tyre	No. of 63-inch OTR tyre
Typical flat bed	6 to 8	3 to 4
Typical trailer B-double	8 to 10	3 to 4
Shipping method	Lying down	Standing up

Due to the high variation in collection distances and truck types, a range of truck types and distances should be modelled to illustrate potential range of transportation impacts. Considering the bulk nature of tyres, the capacity of each truck is more restricted by the volume of tyres. Moreover, the truck does not run empty on the journey to the collection point. The approximate capacity of different truck types is based on tyre volumes.

Physical Deconstruction

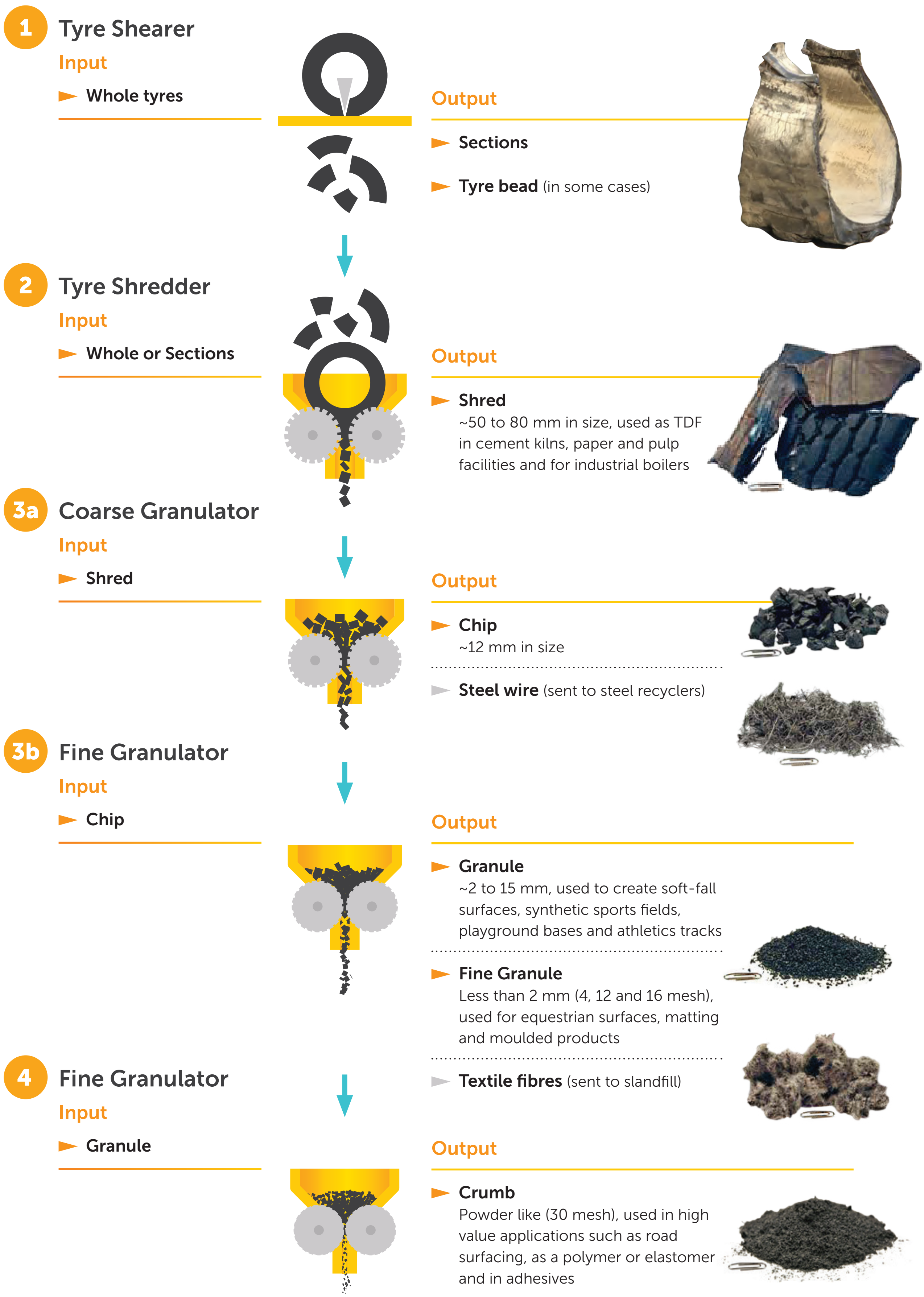
3.3

This study aims to explore TDPs from EOL OTR tyres by physical deconstruction processes, including snipping, shredding, granulating, and crumbing, which diagram is shown in Figure 5, and the general processes involved are:

- **Snipping:** A whole tyre is snipped into 1-4 sectioned tyres
- **Shredding:** The sectioned tyres are shredded to create coarse shreds and remove steel scrap
- **Granulating:** The shreds are granulated into granules and fine rubber granules
- **Crumbing:** The granules are milled into the crumbs

Collected EOL OTR tyre are snipped into smaller pieces and processed through tyre shredders to remove steel scrap and create rubber shreds, of which the composition of steel/fibre is assumed to be the same as passenger and truck tyres, more research and data is needed to assess the proportions of OTRs. The shreds can be used as TDF, and the steel scrap is sent to recyclers. The shredded tyres can undergo further processing through tyre granulators, creating various grades of granules. Further processing creates a powder called crumb rubber. Each of these processing stages requires additional energy. There is, therefore, a trade-off between the added environmental impacts and processing costs and the opportunity for higher value applications.

Figure 5: Process diagram for the physical decomposition of truck tyres (adapted from Rouwette, 2020 and Matt et al., 2017)



Life Cycle Assessment Scenarios 4

Goal 4.1

The goal of this study is to quantify the global warming potential (GWP) and wider environmental impacts for five recovery scenarios for EOL OTR tyres. Specifically this will involve modelling the impacts for processing either agriculture and mining tyres into tyre-derived products (rubber shreds, granules, and crumb rubber). It also aims to investigate the potential benefits from different recovery pathways of OTR tyres and help identify solutions for improving recovery rates.

Scope 4.2

The study considers the environmental impacts and potential benefits of recovering agriculture and mining OTR tyres at their EOL stage, from OTR used tyre collection to the manufacturing of TDPs, by five recovery pathways. The TDPs are coarse shreds, granules with various grades, and crumbs, depending on the recovery processes. All the recovery processes and associated activities require raw material, energy, and water inputs, which are the direct impacts attributed to the recovery of OTR tyres. However, the benefit from recycling steel as the avoidance of virgin material is out of scope.

Five recovery pathways, two for agricultural OTR tyres and three for mining OTR tyres, were scoped and modelled in this study; the tyre type, transport distances and processing steps for each of the five scenarios (A1-A2, M1-M3) are outlined in Figure 8.

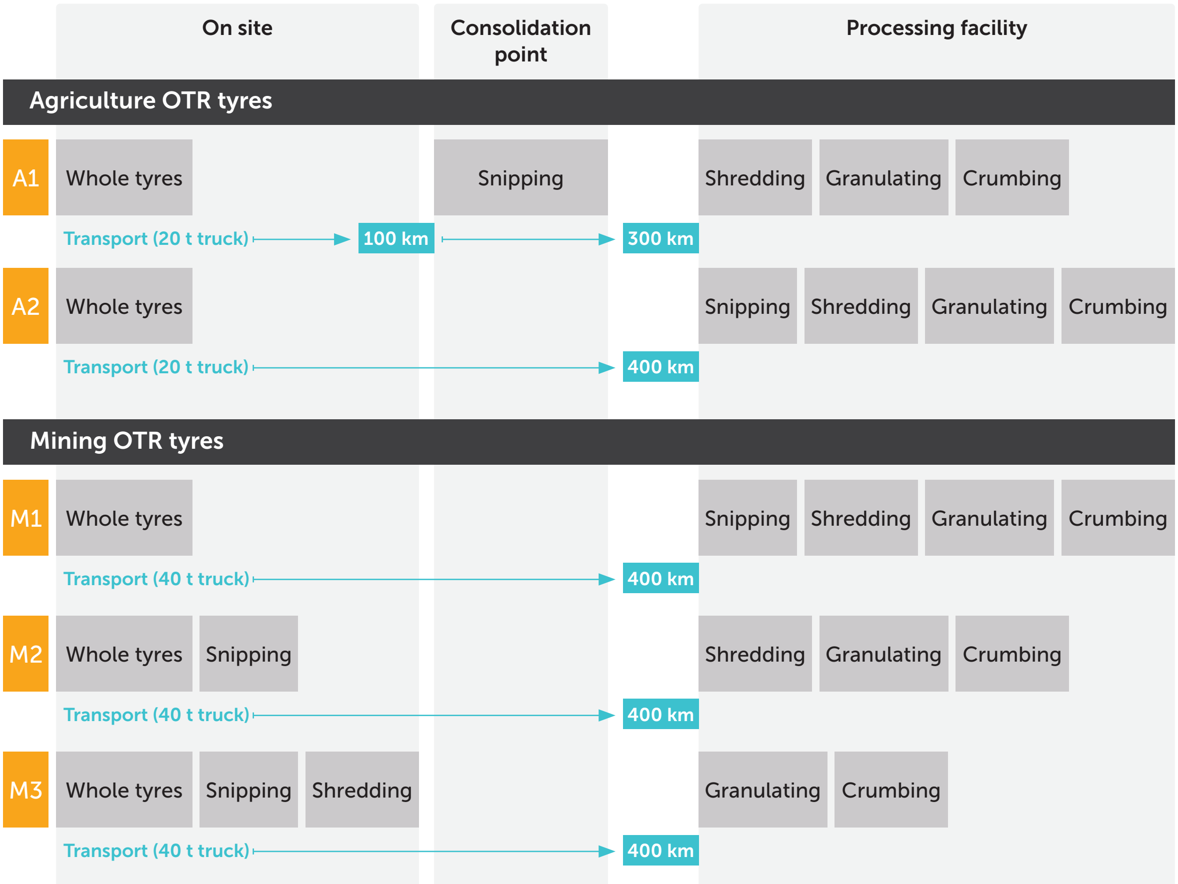


Figure 8: Scenarios modelled for agriculture and mining OTR tyres

Functional Unit

4.3

The functional unit is a measure of the function of the studied product system, providing the baseline reference to which the inputs and outputs of each system can be compared. In this study, the functional unit is **1 t of OTR tyre** to be picked up on site and it will be recovered as crumb rubber.

System Diagram and Boundary

4.4

Figure 9 provides a summary of whole life cycle of a OTR tyre, with a particular focus on the expected recovery processes of agriculture and mining OTR tyres. The figure displays the system boundary included in this study, which starts with the collection and transport of EOL OTR tyres and ends with TDPs and their co-products. Data for snipping, transport and mobile shredding is new information and data compiled in this study, with other process data is drawn on from previous TSA research (Rouwette 2020, TSA 2024).

Further recycling and end-markets data for OTR tyres was out of scope for this study, as they have been assessed in previous research (TSA 2024).

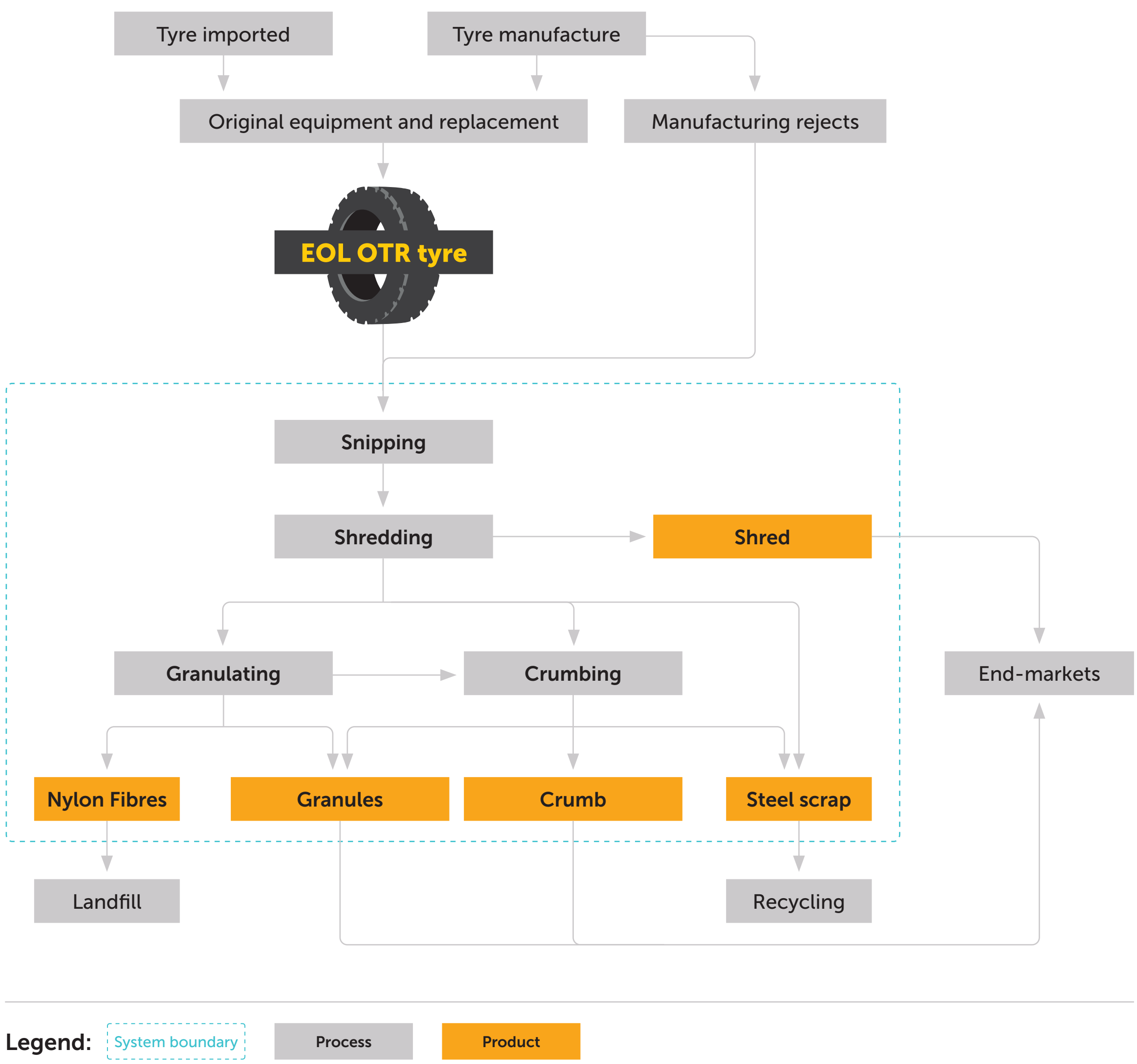


Figure 9: Process flow and system diagram for EOL OTR tyre recycling, showing system boundary for current assessment

Assumptions 4.5

To make the study more feasible, several assumptions are made to response to the lack of data:

- The *Tipping the balance* report proposes reverse logistics to pick up EOL OTR tyre, therefore it is assumed that the truck is always loaded and the fraction of time for loads equals to 1.
- When delivering the whole OTR tyre, truck is limited by the capacity. In this instance, an average load 800 EPU equivalent of 6.4 t represents to capacity of 20 t truck following the previous study (TSA 2024, and 2500 EPU equivalent of 20 t (four 63 inch OTR tyres) is assumed to be the capacity of 40 t truck.
- It is assumed 5 t of OTR tyre can be processed by forklift and snipping machinery per hour.
- If the snipping and shredding processes are conducted on site, the mobile machinery transport is assumed to be 200 km. They can be transported by either one or two trucks depending on the capacity of the truck and the availability of the machinery. While the machinery runs 10 hours per day and 5 days per week according to the recycler, it is assumed the machinery operates a week on site, processing 250 t of OTR tyres in total.
- The benefit from recycling steel scrap as the avoidance of virgin material is out of scope based on cut-off criteria. No potential environmental credits are taken from co-products generated during OTR recycling and recovery pathway.

Geographic and Temporal Coverage 4.6

The intended geographical scope is Australia. The time reference is the calendar year 2023, with the data sourced to reflects current technology and energy mixes.

Project Assessment Methodology 4.7

The life cycle impact assessment (LCIA) method and indicators used in this study are listed in Table 4. The GHG emissions quoted in this report refers to 'Global warming potential – Total', which are split into three sub-categories, fossil, biogenic, and land use.

Table 4: Life cycle impact categories, measurement units and methods used in this study

Impact Category	Description	Measurement Unit	Assessment Method and Implementation
Global warming potential (fossil) (GWP fossil)	Estimates global warming potential (GWP) of GHG emissions resulting from the oxidation or reduction of fossil fuels or fossil carbon substances.	kg CO_2 eq.	Baseline model of 100 years of the Intergovernmental Panel on Climate Change (IPCC) based on IPCC 2013
Global warming potential (biogenic) (GWP biogenic)	Estimates the GWP of GHG emissions resulting from biomass.	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013

Impact Category	Description	Measurement Unit	Assessment Method and Implementation
Global warming potential - Land use and Land use change (GWP land use)	Estimates GHG warming effect for land use and land use change.	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
Global warming potential – Total (GWP total)	Estimates the total GHG warming effect. This is a sum of the GWP fossil, GWP biogenic and GWP land use categories.	kg CO_2 eq.	Baseline model of 100 years of the IPCC based on IPCC 2013
Eutrophication, terrestrial	Estimates the potential increment of nutrients in land.	mol N equivalent	Accumulated Exceedance, Seppälä et al. 2006, Posch et al.
Ecotoxicity, freshwater	Estimates the potential impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil.	CTUe	USEtox
Water scarcity	Estimates the potential of water deprivation, to either humans or ecosystems, and serves in calculating the impact score of water consumption at midpoint in LCA or to calculate a water scarcity footprint as per ISO 14046.	m^3 equivalent deprived	Available Water Remaining Boulay et al., 2016
Resource use - fossil	Estimates the impact on fossil fuels reserves.	MJ	CML (v4.1)

Life Cycle Inventory 5

Background data 5.1

The inventory data for the processes is fed into SimaPro (v9.5.0.0) LCA software and linked to the pre-existing data for the upstream feedstocks and services.

Inventory data was selected per the standards, in the following order of preference:

- The Australian Life Cycle Inventory (AusLCI) v1.42, released in 2023, is being compiled by the Australian Life Cycle Assessment Society (ALCAS). This database was prioritised to model the processes within Australia.
- Ecoinvent 3.9.1 database (Ecoinvent Center, 2023) was modified and used when AusLCI lacks appropriate processes. When possible, the process will be linked to the background data from AusLCI.
- Australasia v2014.09 database was used to extract the amount of energy use for several machineries only.

Edge complied with seven additional criteria in selecting data for modelling:

- Relevance: select sources, data, and methods appropriate to assessing the chosen product's life cycle inventory (LCI).
- Completeness: include all LCI items that provide a material's contribution to a product's life cycle emissions.
- Consistency: enable meaningful comparisons in LCIA information.
- Accuracy: reduce bias and uncertainty as far as is practical.
- Transparency: when communicating, disclose enough information to allow third parties to make decisions.
- Time coverage: the data collected represents recent practice for the construction of the project, and
- Geographical coverage: the data collected are representative of the sourcing of materials, whether from Australia or overseas and are in line with the goal of the study.

In line with the completeness requirement, certain cut-off rule is applied to the study. Environmental impacts from infrastructure, production equipment, and tools that are not directly consumed in the production process are not accounted for in the LCI.

Collection and Processing Data 5.2

Collection and transport 5.2.1

The collection of EOL OTR whole tyres is largely restricted by volume due to the bulk nature of tyres, and it will be done in reverse logistics operated by tyre service provider. In this case, assuming 20 t, and 40 t trucks are employed as the typical truck types with a carrying capacity shown in Table 5. According to recyclers, no more than 10 OTR tyres will be collected at each delivery in general, and all OTR tyres that have a rim size equal or less than 57 inch are assumed to be laid down to make use of truck capacity. In addition, a forklift is used to the collection of OTR tyres to the truck.

Table 5: Carrying capacity by truck type

	20 t truck	40 t truck
Length	12.5 m	16 m
Width	2.3 m	3.6 m
Height	2.0 m	3.9 m
Max. payload capacity	20 t	40 t
Approx. capacity*	350-800 EPU	1200-4000 EPU

**Note – each EPU is 8 kg based on TSA (TSA, 2019)*

The environmental impact of transport is determined by the transport distance and the load it carries. When the snipping process is conducted to downsize the OTR tyre, more OTR tyre pieces are able to be delivered at a time allowing for the efficient use of truck's capacity. In this case, the capacities of truck align to the average loads given by AusLCI database, which are 20 t and 40 t respectively.

5.2.2 Snips

To process OTR tyres, they are normally forklifted and cut into 1-4 sections to be fed into shredders. In general, OTR tyre snipping is conducted by a hydraulic excavator and shear, primary data sourced from two Australian tyre recyclers. The efficiency of snipping and its energy consumption vary depending on the size of the shear and product being cut, therefore 40 L of diesel consumed per hour will be used as a typical energy consumption of snipping in the study, suggested by a tyre recycler. According to snipping machinery instructions available online, it is assumed around 5 t of OTR tyre can be processed per hour. Table 6 shows LCI for the tyre snipping process. In the process, no weight loss of OTR tyre is taken into account as the potential wastes and co-products are integrated into the shredding process, which will be demonstrated in Section 6.2.3.

Table 6: Life cycle inventory for conversion of 1 t EOL OTR tyre into snipped OTR tyre section

Category	Process	Unit	Amount
Inputs			
Raw Material	EOL OTR tyre, at tyre recycling plant	tonne	1.0
Energy	Diesel	L	10.841
Outputs			
Product	Snipped OTR tyre, at tyre recycling plant	tonne	1.0

The snipping process occurs either on site or at tyre recycling plant, associated with the transport of machinery. If the snipping process is on site, a hydraulic excavator and shear with the weight of 30 t, is delivered by a 40 t truck. Assuming the transport distance of machinery is half of the delivery service distance, that is, 200 km. This activity results in an additional impact in the recovery pathway but improves the capacity of tyres able to be transported by truck, which was limited by the tyre size.

Shreds, granules, and crumbs

5.2.3

Table 7 to Table 9 give insights into LCIs for the tyre shredding, granulating, and crumbing processes respectively. These have been sourced via primary data, and provide a representative sample of Australia's tyre recycling industry (Rouwette 2020). Full details on the shredding, granulating and crumbing data is outlined previous research (TSA Study). It's noted that in this study the steel scrap is separated in the shredding step, although it should be removed at every point in the processes.

Table 7: Life cycle inventory for conversion of 1 t EOL tyre into shredded rubber in a tyre shredder (Rouwette, 2020)

Category	Process	Unit	Amount
Inputs			
Raw Material	Snipped OTR tyre, at tyre recycling plant	tonne	1
Energy	Electricity from grid	kWh	19.897
Energy	Diesel	L	2.137
Energy	LPG	kg	0.619
Outputs			
Product	Shredded rubber, at tyre recycling plant	tonne	0.737
Co-Product	Steel scrap, at tyre recycling plant	tonne	0.263

Table 8: Life cycle inventory for conversion of 0.737 t shredded rubber from 1 t EOL tyre input into rubber granules in tyre granulator (Rouwette, 2020)

Category	Process	Unit	Amount
Inputs			
Raw Material	Shredded rubber, at tyre recycling plant	tonne	0.737
Energy	Electricity from grid	kWh	92.852
Energy	Diesel	L	2.137
Energy	LPG	kg	0.619
Outputs			
Product	Rubber granules, at tyre recycling plant	tonne	0.737
Waste	Nylon fibres from waste tyres	tonne	3.7E-5

Table 9: Life cycle inventory for conversion of 0.737 t rubber granules from 1 t EOL tyre input into crumb rubber in tyre crumbing (Rouwette, 2020)

Category	Process	Unit	Amount
Inputs			
Raw Material	Rubber granules (<15 mm), at tyre recycling plant	tonne	0.737
Energy	Electricity from grid	kWh	364.020
Energy	Diesel	L	2.137
Energy	LPG	kg	0.619
Outputs			
Product	Crumb rubbers, at tyre recycling plant	tonne	0.737
Waste	Nylon fibres from waste tyres	tonne	3.7E-5

EOL tyres are shredded in tyre shredders, the output is then forklifted to tyre granulators to be processed into granules. The shredded rubber undergoes further processing into granules (as in Table 8), which impacts are assigned to the granules and waste is sent to landfill. Afterwards, the granules are processed by tyre mills into crumb rubbers, which LCI is shown in Table 9, as the end market product. As a result, to process 1 t of OTR tyres, around 0.737 t of crumb rubber is recovered, with 0.263 t of steel scrap for recycling and 0.074 kg of textile fibres for disposal.

Considering the benefit brought from co-product recycling, if the steel scrap is sold to steel recyclers, further offsets from recycled steel can be achieved when quantifying the environmental impact of recovery pathways.

Life Cycle Assessment Results 6

Impacts from Tyre Collection and Transport 6.1

Table 10 summarises the environmental impact of collecting/lifting 1 t of OTR tyres, and transporting them for 1 km. The emissions per tonne per kilometre for OTR tyres are at least 50% lower if the tyres are cut before transport. The cutting process reduces the tyre size, significantly enhancing packing efficiency. Additionally, transporting tires by a 40 t truck results in lower emissions compared to a 20 t truck. This highlights the importance of using larger trucks, provided they can be fully loaded for each trip.

Table 10: Environmental impact of OTR tyre collection and transport activities

Process	GWP-T kg CO_2 eq.	Eutrophication, terrestrial mol N eq.	Ecotoxicity, freshwater CTUe	Water scarcity m^3 eq. deprived	Resource use – fossil MJ
Collection					
1 t of tyre	8.99	0.392	213.47	1.626	2.660
Transport – before pre-processing					
1 tkm of whole tyre, by 20 t truck	0.244	7.27E-03	0.943	2.11E-02	3.284
1 tkm of whole tyre, by 40 t truck	0.097	1.60E-03	0.381	8.43E-03	1.311
Transport – after pre-processing					
1 tkm of snipped tyre, by 20 t truck	0.078	2.33E-03	0.302	6.76E-03	1.051
1 tkm of snipped tyre, by 40 t truck	0.049	8.02E-04	0.191	4.21E-03	0.656

Impacts from Tyre Processing

6.2

Table 11 gives the detail insights into the potential environmental impact of recycling 1 t of EOL OTR tyres under different processing activities. The results only take into account the activity itself, which exclude emissions of OTR tyre collection and transport, and recovery of co-product. It indicates that the conversion of EOL tyres into products of finer grading significantly escalates the environmental impact due to the additional energy needs. Shredding, granulating, and crumbing processes generate around 2, 9, and 36 times higher GHG emissions compared to snipping process, and such an increasing trend applies to all other environmental impact categories. Notably, the impact of resource use – fossil category is more influential by energy use, diesel and electricity in the case, of which electricity from grid is the main contributor. Eutrophication, terrestrial and water scarcity are also predominantly controlled by electricity consumption when analysing the contribution of input materials. Freshwater ecotoxicity has less noticeable varies compared to other impact category, although more energy-intensive process leads to the higher impact. It is affected by diesel and electricity simultaneously, but the indicator is less sensitive to electricity consumption.

Table 11: Environmental impact of TDPs recovered from OTR tyres

		GWP-T	Eutrophication, terrestrial	Ecotoxicity, freshwater	Water scarcity	Resource use – fossil
Process	Product	kg CO_2 eq.	mol N eq.	CTUe	m^3 eq. deprived	MJ
Snipping	1 t of snip	12.389	0.422	814.547	6.203	10.149
Shredding	1 t of shreds	37.965	0.722	1368.107	12.434	264.823
Granulating	1 t of granules	124.981	1.718	1703.616	25.258	712.458
Crumbing	1 t of crumbs	461.758	5.589	2284.098	69.930	2390.353

Australia's electricity grid is currently composed of 68% of fossil fuels, and 32% of renewables, with nearly half of the total being coal (DCCEEW, 2023). This explains to the significant increase in impact categories when finer graded products are manufactured. While the coal is largely used for generating electricity, there's also a trend that the share of coal in the electricity mix is declining and more renewable energy is generated. In line with the change of Australian electricity mix, it can be expected that the emissions of processing activities keep falling, but it will differ from states.

Environmental Impact of Five Scenarios

6.3

Analysis was done by scenarios referring to Figure 10, and Table 12 to Table 16 present the total environmental impact for processing 1 t of OTR tyres to crumb rubber in different impact categories. In the 5 scenarios finalised in Figure 10, granulating and crumbing processes currently only occur at dedicated processing facilities, but snipping and shredding can be on-site or off-site. Scenarios M2 and M3 require mobile machinery to be transported to the site, generating additional impacts from this activity. In line with the assumption, 250 t of OTR tyres are processed at a time, and the emission of transporting machinery is equally allocated to these tyres. However, there's no difference between on-site and off-site snipping and shredding processing, because the machinery applied and corresponding energy use are identical. Therefore, the main differences of impacts of OTR tyre recovery come from the transport related settings, including transport distance of whole and snipped tyres, delivery of mobile machinery to the site, and the needs of consolidation point.

Figure 10: Five scenarios in the analysis

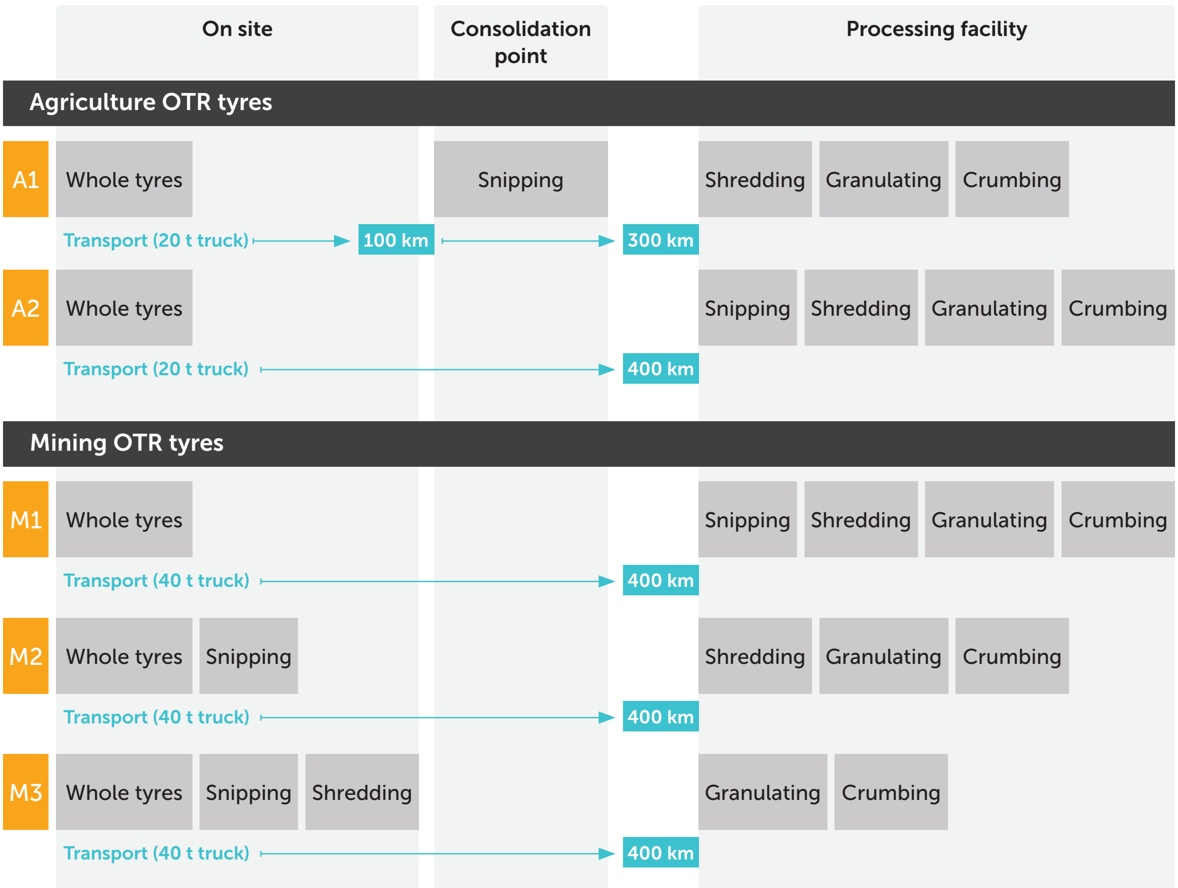


Table 12: GWP-T of processing 1 t of OTR tyres

	Agriculture		Mining		
GWP-T (kg CO_2 eq.)	Scenario A1	Scenario A2	Scenario M1	Scenario M2	Scenario M3
Transporting of OTR tyre	56.84	106.65	47.84	19.42	14.31
Transporting of machinery	0	0	0	1.66	3.33
Snipping	12.39	12.39	12.39	12.39	12.39
Shredding	15.59	15.59	15.59	15.59	15.59
Granulating	64.12	64.12	64.12	64.12	64.12
Crumbing	248.15	248.15	248.15	248.15	248.15
Total	**397.09**	**446.89**	**388.08**	**361.33**	**357.89**

Table 13: Eutrophication, terrestrial of processing 1 t of OTR tyres

	Agriculture		Mining		
Eutrophication, terrestrial (mol N eq.)	Scenario A1	Scenario A2	Scenario M1	Scenario M2	Scenario M3
Transporting of OTR tyre	1.82	3.30	1.03	0.32	0.24
Transporting of machinery	0	0	0	0.03	0.06
Snipping	0.42	0.42	0.42	0.42	0.42
Shredding	0.11	0.11	0.11	0.11	0.11
Granulating	0.73	0.73	0.73	0.73	0.73
Crumbing	2.85	2.85	2.85	2.85	2.85
Total	**5.94**	**7.42**	**5.15**	**4.47**	**4.41**

Table 14: Ecotoxicity, freshwater of processing 1 t of OTR tyres

	Agriculture		Mining		
Ecotoxicity, freshwater (CTUe)	Scenario A1	Scenario A2	Scenario M1	Scenario M2	Scenario M3
Transporting of OTR tyre	398.43	590.93	366.07	76.30	56.23
Transporting of machinery	0	0	0	6.54	13.08
Snipping	814.55	814.55	814.55	814.55	814.55
Shredding	193.64	193.64	193.64	193.64	193.64
Granulating	247.18	247.18	247.18	247.18	247.18
Crumbing	427.66	427.66	427.66	427.66	427.66
Total	**2081.46**	**2273.96**	**2049.10**	**1765.87**	**1752.34**

Table 15: Water scarcity of processing 1 t of OTR tyres

	Agriculture		Mining		
Water scarcity (m^3 eq. deprived)	Scenario A1	Scenario A2	Scenario M1	Scenario M2	Scenario M3
Transporting of OTR tyre	5.76	10.07	4.80	1.69	1.24
Transporting of machinery	0	0	0	0.14	0.29
Snipping	6.20	6.20	6.20	6.20	6.20
Shredding	2.96	2.96	2.96	2.96	2.96
Granulating	9.45	9.45	9.45	9.45	9.45
Crumbing	32.92	32.92	32.92	32.92	32.92
Total	**57.29**	**61.60**	**56.53**	**53.36**	**53.06**

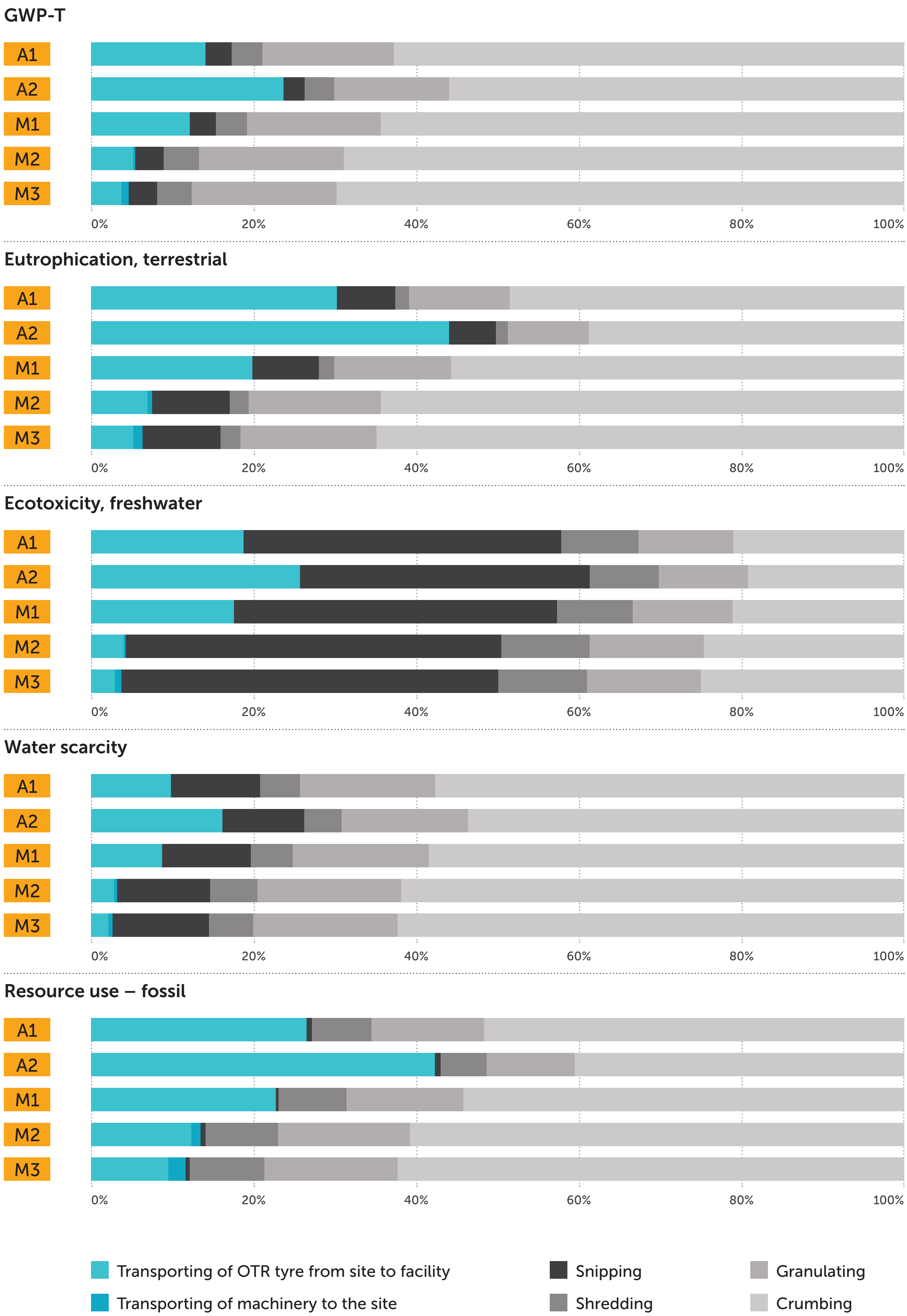
Table 16: Resource use – fossil of processing 1 t of OTR tyres

	Agriculture		Mining		
Resource use – fossil (MJ)	Scenario A1	Scenario A2	Scenario M1	Scenario M2	Scenario M3
Transporting of OTR tyre	646.32	1316.25	527.14	262.24	193.25
Transporting of machinery	0	0	0	22.48	44.96
Snipping	10.15	10.15	10.15	10.15	10.15
Shredding	185.00	185.00	185.00	185.00	185.00
Granulating	329.84	329.84	329.84	329.84	329.84
Crumbing	1236.32	1236.32	1236.32	1236.32	1236.32
Total	**2407.64**	**3077.57**	**2288.46**	**2046.04**	**1999.53**

Among all the processes across all environmental impact categories and scenarios, crumbing process is overall the highest contributor, except for terrestrial eutrophication in Scenario A2 and freshwater ecotoxicity, as shown in Figure 11. Crumbing leads to 19% to 69% of total environmental impact, while the sum of snipping, shredding, and granulating processes has much less impacts compared to it in GWP-Total, terrestrial eutrophication, water scarcity, and resource use – fossil. However, snipping has a significant impact (36% to 46%) in terrestrial eutrophication, led by diesel used for machinery operation.

Transport related activities contributes to 3% to 44% of environmental impacts in all scenarios, which is more obvious in Scenario A2. In Scenario A2, considering the relatively lighter weight and smaller size the agricultural OTR tyre has, a 20 t truck is sufficient for delivery purpose. Its emission on a per tonne per km basis is higher than a 40 t truck, especially when the OTR tyre is not pre-processed, as shown in Table 10.

Figure 11: Contribution of each process across all environmental impact categories and scenarios



Agricultural OTR tyre

6.3.1

When comparing two scenarios for agricultural OTR tyre recovery (Figure 12), Scenario A1 appears to have lower environmental impacts compared to Scenario A2 when a consolidation point for tyre snipping is set up near the site. The reductions of all assessed impact categories range from 7% to 22% when consolidation point is introduced. Under the current scenario, consolidation point is assumed on the straight way from the site to processing facility, and total transport distance is 400 km that is same as A2. However, it is sometimes not possible to achieve if one consolidation point covers multiple sites. Further investigations on the establishment of consolidation point regarding its location, the coverage area, and the trade-off between cost and environmental benefits should be done.

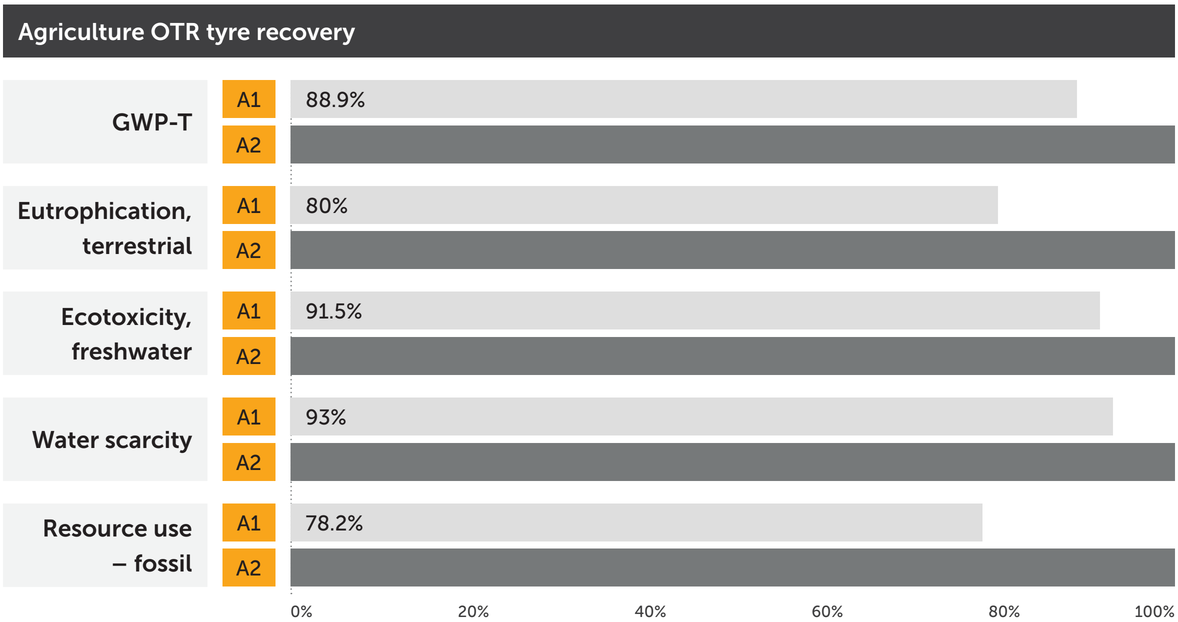


Figure 12: Relative impact of Scenario A1 against Scenario A2 under assessed impact categories

The significant results are therefore understood as a consolidation point within a 100 km of radius of the site, offering environmental benefits when the transport distance between the site and processing facility equals to or exceeds 400 km.

Mining OTR tyre

6.3.2

Scenarios M1-M3 are focused on mining OTR tyre recovery pathways, and the difference is the location of snipping and shredding processes. In Figure 13, relative impact of three scenarios is presented using Scenario M1 as a baseline, and Scenario M3 performs the best in every single indicator among three scenarios.

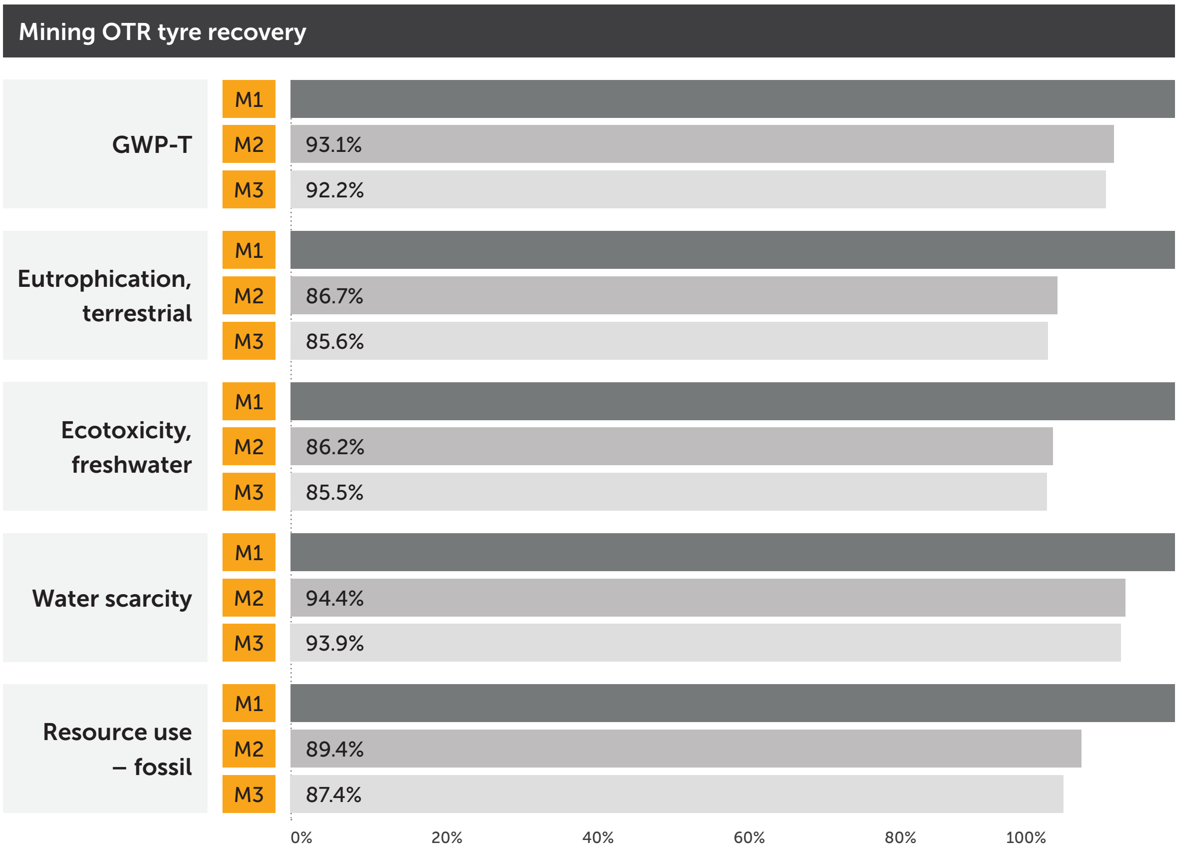


Figure 13: Relative impact of Scenarios M2 and M3 against Scenario M1 under assessed impact categories

Scenario M1 considers the transport of whole tyre to processing facility for further processes, Scenario M3 makes use of mobile snipping machinery on-site to downsize the tyre, and takes on-site shredding into account. In these scenarios, mobile machinery is assumed to be transported to the site, processing 250 t of OTR tyres in total. The use of mobile machinery provides considerable benefits in Scenarios M2 and M3, resulting in 6% to 14% reductions compared to Scenario M1 from the overall impacts' perspective. The size of mining OTR whole tyre is the main challenge influencing the load capacity and efficiency of truck, and pre-processing (snipping) before an OTR tyre is sent to recycling demonstrates important environmental benefits.

When looking at Scenarios M2 and M3, mobile shredding machinery can further reduce the size of OTR tyre pieces and accordingly cut down the environmental impact of whole recovery pathway, but this advantage is marginal (around 1% difference). This is because the snipping process has overcome the barrier from bulk nature of mining OTR tyre and 40 t truck has been used efficiently. Comparison results indicate that the management of transport should be highlighted when recycling, regarding both transport distance and route between the site and processing facility, and delivery of mobile machinery. In addition, less variation between Scenarios M2 and M3 implies that the delivery of shredding machinery to a remote site might be avoided if it is a long-distance transport. Again, a detailed analysis is required for such an exploration to have a consolidated conclusion and support to decision-making.

The main findings suggest that snipping mining OTR tyres on-site for transport demonstrates environmental benefits by enhancing the efficiency of bulk transport of tyres. However, on-site shredding, while providing a modest advantage, is offset by the increased distance required for transporting the shredding equipment. This largely nullifies the benefits gained by reducing the bulk nature of the tyres from snipped to shredded.

Sensitivity Analysis 6.4

The location of OTR tyre to be collected is one of the key factors influencing the environmental performance of EOL OTR tyre recovery. This is associated with the transport distance between the site and processing facility, the necessity of consolidation point, and whether mobile machinery should be delivered to the site for pre-processing. Since the transport distance varies greatly, sensitivity analysis should be implemented to test and explore key assumptions, data uncertainties, and to provide a depth of information to meet the goals.

The following assumptions are examined:

- Collection and transport distance of agricultural EOL OTR tyre
- Delivery of mobile machinery and its processing amount in a trip

Impact of collection and transport of OTR tyre 6.4.1

In line with *Tipping the balance* and expert opinion, 200 km of agricultural OTR tyre transport is practical in some states. While in larger states with remote agriculture settings, 200 and 500 km are assumed as the maximum distance to consolidation point and processing facility, respectively. Based on the information provided, two alternative cases are explored for agricultural OTR tyre recovery, which transport arrangements are listed below in Table 17.

Table 17: Sensitivity analysis setting for agricultural OTR tyre based on Scenarios A1 and A2

Scenario A1	**Case 1**	**Case 2** (current A1 setting)	**Case 3**
Site to consolidation point	50 km	100 km	200 km
Consolidation point to processing facility	150 km	300 km	500 km
Scenario A2	**Case 1**	**Case 2** (current A2 setting)	**Case 3**
Site to processing facility	200 km	400 km	500 km

Table 18 and Figure 14 show the impact of adjusting the transport distance between the site and processing facility for collecting and transporting agricultural OTR tyre in assessed indicators. Distances can be highly variable depending on the location of the waste tyres, particularly in regional locations. The change of transport distance has relatively higher influence in GHG emissions (15% of variation), terrestrial eutrophication (17% of variation), and fossil resource use (19% of variation), which is valid both for Scenarios A1 and A2. When comparing cases across two scenarios, overall environmental impact is more sensitive to the shortening of the transport from site to consolidation point. As a result, transport between site and consolidation point should be more focused on when catchment-based consolidation point is planned and managed, trying to cover more farm sites whilst minimising the distance.

Table 18: Potential environmental impact of recovering 1 t of agricultural OTR tyres with different transport distances

Agricultural OTR tyre		Scenario A1 (Site – Consolidation point – Processing facility)			Scenario A2 (Site – Processing facility)		
Indicator	Unit	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
GWP – T	kg CO_2 eq.	373.16	397.09	437.13	398.06	446.89	471.31
Eutrophication, terrestrial	mol N eq.	5.22	5.94	7.13	5.96	7.42	8.15
Ecotoxicity, freshwater	CTUe	1988.98	2081.46	2236.22	2085.23	2273.96	2368.33
Water scarcity	m^3 eq. deprived	55.22	57.29	60.75	57.38	61.60	63.71
Resource use – fossil	MJ	2085.81	2407.65	2946.21	2420.78	3077.57	3405.97

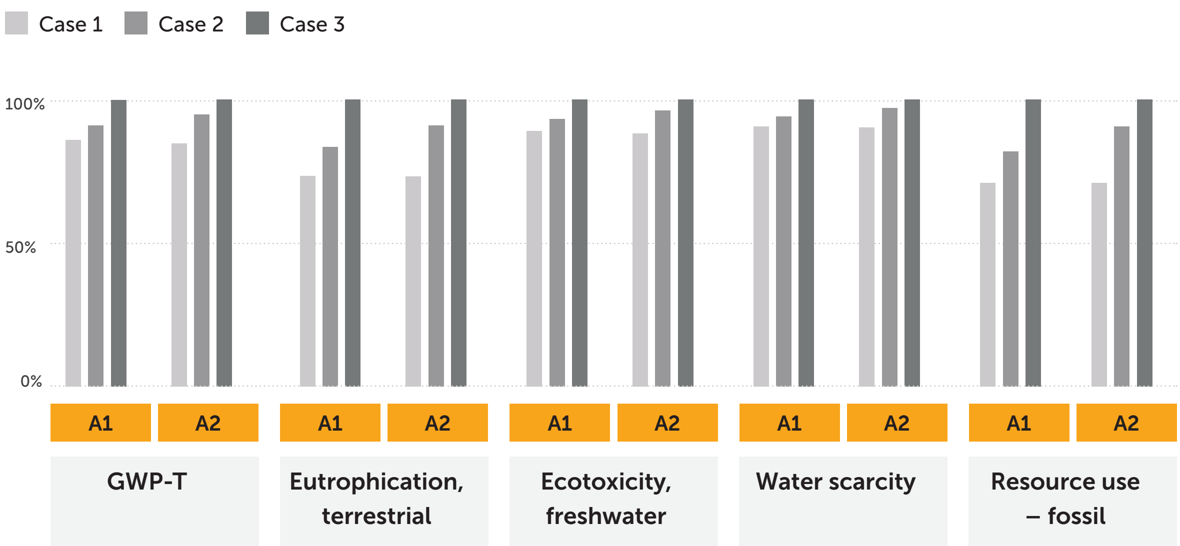
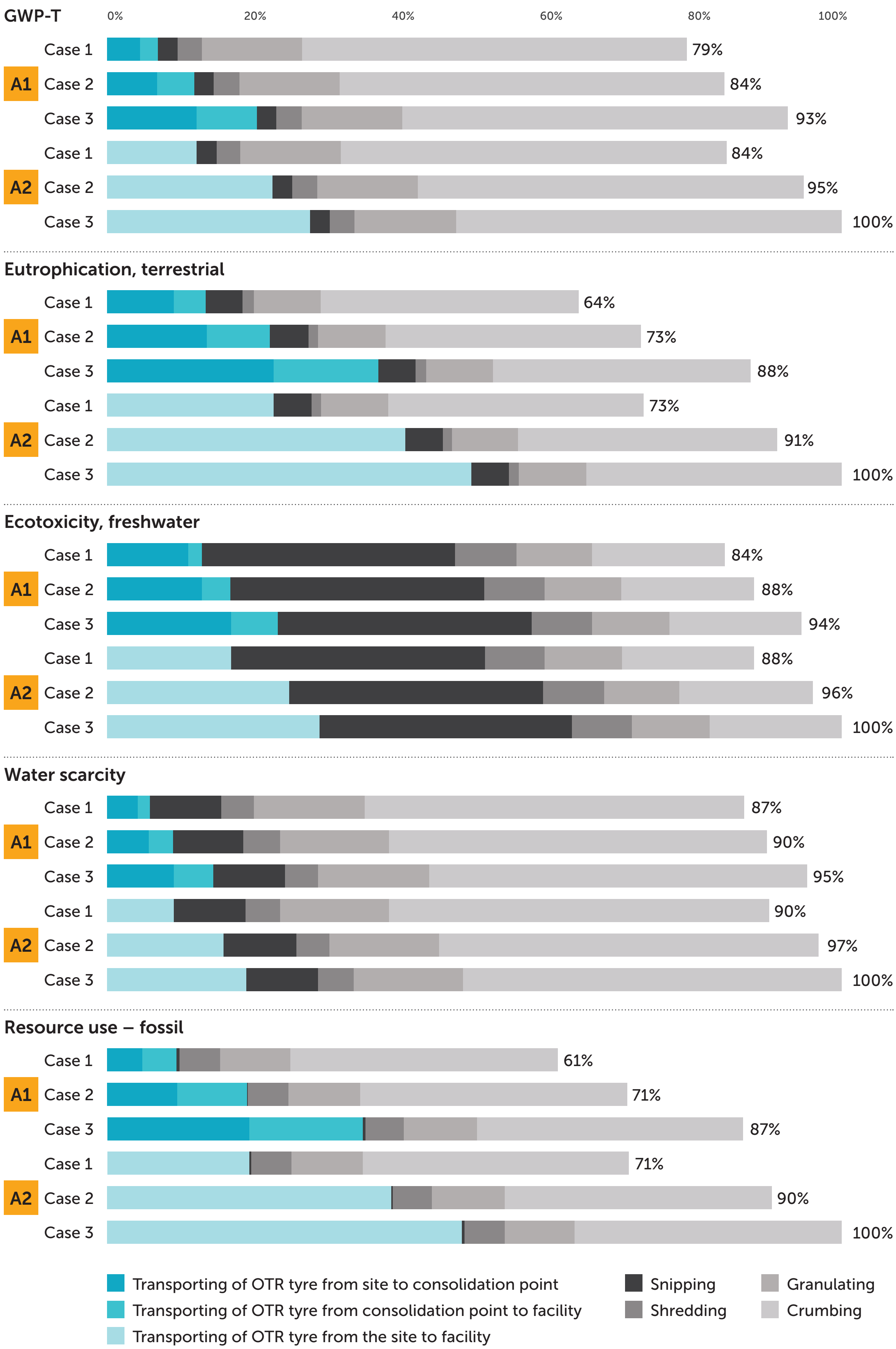


Figure 14: Sensitivity analysis of altering transport distance between site and processing facility for agricultural OTR tyres

When comparing all the cases in two proposed scenarios for the recovery of agricultural OTR tyre, Scenario A2 – Case 3 exhibits the highest environmental impact. This assumes a direct transport of OTR tyres from the site to the processing facility as 500 km. To better understand the potential benefits arising from the establishment of consolidation point, an analysis of six cases is conducted and compared. Figure 15 provides a clearer picture of the contribution of associated processing activities to the environmental impact of agricultural OTR tyre recovery. In instances with the same transport distance, such as Case 1 and Case 2, the presence of a consolidation point greatly saves non-renewable energy consumption, and other impacts are reduced accordingly. Even in an extreme case (Case 3), where the total transport distance is 200 km higher than direct transport in Scenario A2, introducing a consolidation point still results in an overall environmental impact that is 3% - 10% lower when processing agricultural OTR tyre. It demonstrates the necessity of implementing a consolidation point if the transport of agricultural OTR tyre is a significant component involved in the recovery pathway.

Figure 15: Breakdown of contribution of processing activities to the environmental impact of agricultural OTR tyre recovery (Scenario A2 – Case 3 has the highest impact in all assessed impact categories, which is referred as 100% of impact in the figure for the comparison purpose)



Impact of delivery and processing of mobile machinery

6.4.2

It is anticipated that the relative proportion of mining OTR tyres collected and pre-processed is high initially and may reduce over time. It means the amount of mining OTR tyre mobile machinery can process each trip varies with the availability of tyres. Table 19 shows the sensitivity analysis setting for mining OTR tyres considering different processing amount per trip. In addition, some mining sites may already have machinery presented on-site, from which case 4 is prepared representative of on-site machinery available.

Table 19: Sensitivity analysis setting for mining OTR tyre based on Scenarios M2 and M3

Scenario M3	Case 1	Case 2 (current M2 setting)	Case 3	Case 4 (mobile machinery is on-site)
Transport distance of mobile machinery	200 km	200 km	200 km	0 km
Processing amount per trip	100 t	250 t	400 t	N/A
Scenario M3	**Case 1**	**Case 2** (current M3 setting)	**Case 3**	**Case 4** (mobile machinery is on-site)
Transport distance of mobile machinery	200 km	200 km	200 km	0 km
Processing amount per trip	100 t	250 t	400 t	N/A

Table 20 and Figure 16 presents the impact of altering the amount of mining OTR tyre processed by mobile machinery each time in assessed indicators. According to the results, having machinery available on-site is the best option (case 4) for four cases in each scenario. The more OTR tyres that are pre-processed on-site per trip, the less environmental impact is attributed to the recovery of 1 t of tyre. However, this only brings small benefits to overall impact (less than 3%), since crumbing is the most energy-intensive activity, which has been analysed in section 7.3. The primary issue lies in the accessibility of machinery, making a 200 km of delivery distance often impractical.

Table 20: Potential environmental impact of recovering 1 t of mining OTR tyre with different processing amounts

Mining OTR tyre		Scenario M3 (snipping on site)				Scenario M3 (snipping and shredding on site)			
Indicator	Unit	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
GWP – T	kg CO_2 eq.	363.83	361.33	360.71	359.67	362.88	357.89	356.64	354.56
Eutrophication, terrestrial	mol N eq.	4.51	4.47	4.46	4.44	4.49	4.41	4.39	4.35
Ecotoxicity, freshwater	CTUe	1775.68	1765.87	1763.42	1759.33	1771.96	1752.34	1747.43	1739.26
Water scarcity	m^3 eq. deprived	53.57	53.36	53.30	53.21	53.49	53.06	52.95	52.77
Resource use – fossil	MJ	2079.76	2046.04	2037.61	2023.56	2066.96	1999.53	1982.67	1954.57

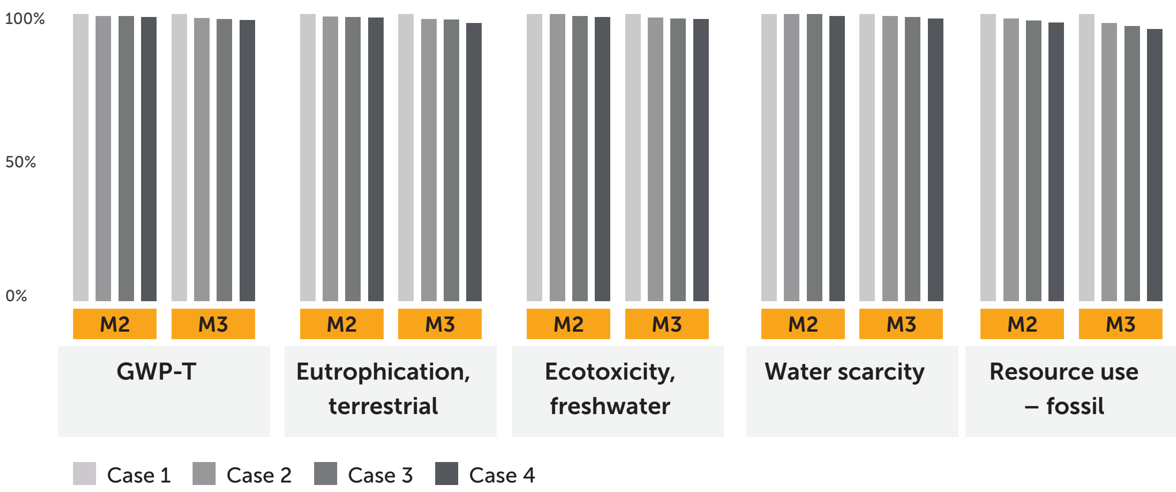


Figure 16: Sensitivity analysis of altering processing amount for mining OTR tyre

Based on the sensitivity analysis, it can be concluded that the amount of mining OTR tyre processed per trip of machinery movement has an insignificant impact on the recovery of mining OTR tyres.

Conclusions 7

In this study, five scenarios were established to investigate the feasibility of recovery pathways for EOL agriculture and mining tyres in terms of environmental performance. Sensitivity analysis was conducted to explore key assumptions, data uncertainties, and to provide a depth of information. There are significant circular economy opportunities possible by establishing reverse logistics and recycling of co-products and aiming for a high recovery rate of OTR tyres.

Based on the results of agriculture and mining tyre recovery scenarios and sensitivity analysis in this study, the main findings are:

1. For agriculture OTR tyres, Scenario A1 had the lowest impacts across all environmental impact categories, with a GWP of 397.09 kg CO_2 eq. for recycling 1 t of tyres.
2. For mining OTR tyres, Scenario M3 had the lowest impacts across all environmental impact categories, with a GWP of 357.89 kg CO_2 eq. for recycling 1 t of tyres.
3. For recovering 1 t of either OTR tyre, around 0.737 t of crumb rubber is produced as the end market product, with 0.263 t of steel scrap for recycling and 0.074 kg of textile fibres for disposal. This is subject to the material compositions of OTR tyre.
4. Crumbing leads to 19% to 69% of total environmental impact assessed, and snipping is the highest contributor to terrestrial eutrophication (36% to 46%), led by diesel used. Transport related activities contributes to 3% to 44% of environmental impacts in all scenarios.
5. Setting up consolidation points helps reduce the overall impact of up to 22%, which is evident from sensitivity analysis of agricultural OTR tyre.
6. The primary impediment to the capacity and efficiency of transport in the case of OTR tyre is their bulk nature. This characteristic restricts the weight that can be loaded compared to standard loads. Nevertheless, it is noteworthy that the implementation of reverse logistics mitigates the environmental impact compared to the dedicated transport.
7. For mining OTR tyre, snipping on site downsizes the tyre prior to be transported, greatly increasing the efficiency of delivery services, and reduce the unit impact from transport process. In sensitivity analysis, the amount of mining OTR tyre processed by mobile machinery during each trip has a relatively minor influence on the overall environmental impact, especially when the machinery is delivered from 200 km away. However, the primary concern centers around the accessibility of machinery, as long-distance transport can introduce considerable impacts throughout the entire process
8. Shredding on site further downsizes the tyre to enable the higher amounts of OTR tyre components to be transported, and reduce the impact accordingly. However, the delivery of shredding machinery to a remote site (e.g., 800 km) may bring a significant environmental impact, and this delivery should be avoided if a long-distance transport is required.

Upon all the findings, the key outcomes are interpretated as follows:

1. Establishing consolidation points proves to be beneficial in mitigating the impact of transport, and the necessity of such points is affirmed in this study. Having a consolidation point within a 100 km of radius of the site demonstrates environmental benefits in the existing scenarios for agricultural OTR tyre recovery.
2. Snipping mining OTR tyres on-site for transport demonstrates significant environmental benefits by enhancing the efficiency of bulk transport of tyres. It should be implemented when collecting and recovering mining OTR tyre. On-site shredding, while providing a modest advantage, is possibly offset by the increased distance required for transporting the shredding equipment. This largely nullifies the benefits gained by reducing the bulk nature of the tyres from snipped to shredded.

Appendix 1
Preliminary Assessment – Case Study

Findings from the initial report *Life cycle assessment of end-of-life tyres* on the benefits of using asphalt binder in road construction has been adjusted to reflect some of the differences in the recovery of OTR tyres.

For this case study, these OTR tyres are assumed to be recovered from an agricultural setting. These tyres are transported from agricultural site to a consolidation point in a regional centre 200 km away. Due to the size and volume of these tyres, a limited number of tyres can be collected at a time. In this scenario, the collection of tyres with an average rim size of 96.5 cm, the median agricultural tyre size is considered. Based on this, it is assumed an average weight is 280 kg, and a tyre diameter is 191 cm.

At the consolidation point, these tyres undergo a coarse shredding process to improve the efficiency of further transport to a crumb rubber processing plant. A full truckload of the shredded OTR tyres is then transported a further 800 km to an urban location where the crumb rubber facility is based. The tyre shreds are mechanically processed into crumb rubber, ready for use in end market products. In this particular scenario, the potential benefits of using the OTR tyres is considered as an asphalt binder in road construction. Figure 17 below presents the recovery pathway explored in this case study.

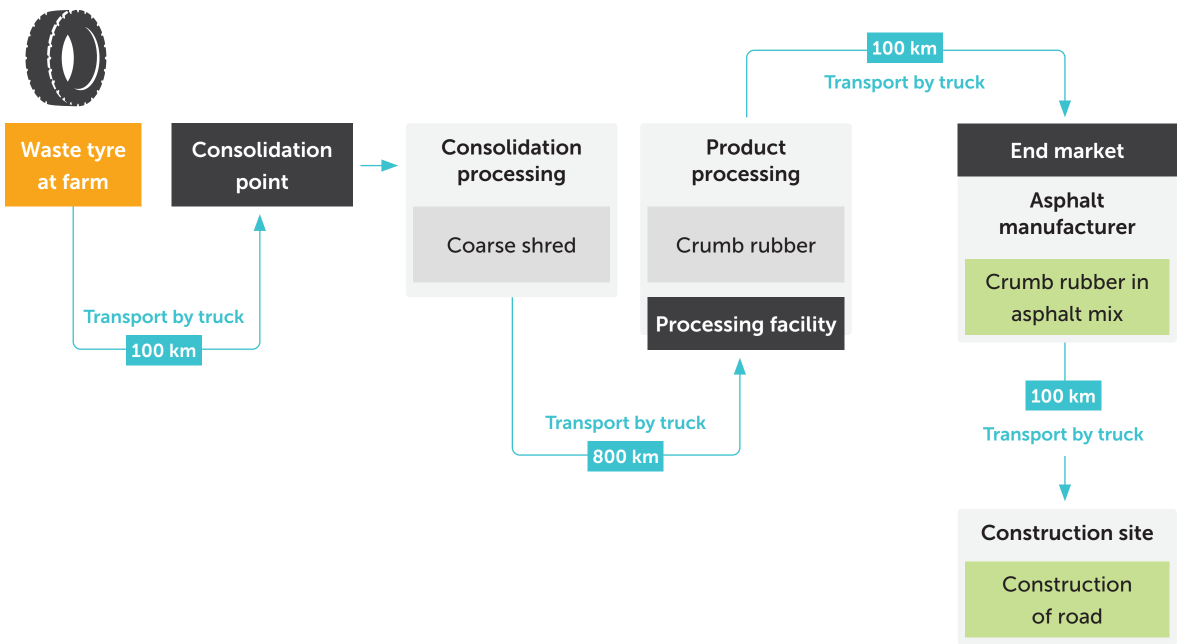


Figure 17: The recovery pathway of agriculture tyre in case study

Preliminary results indicate that the use of crumb rubber derived from passenger and truck tyres has an improvement of 6 – 14% emissions reduction when compared to the conventional fossil-derived polymer modified binders. This is based on a range of asphalt mix designs derived from Australian road construction specifications. While the collection and processing of the agricultural OTR tyre is more emissions intensive compared to passenger and truck tyre processing, preliminary calculations in Figure 18 showed a 4 – 10% improvement compared to the conventional alternative.

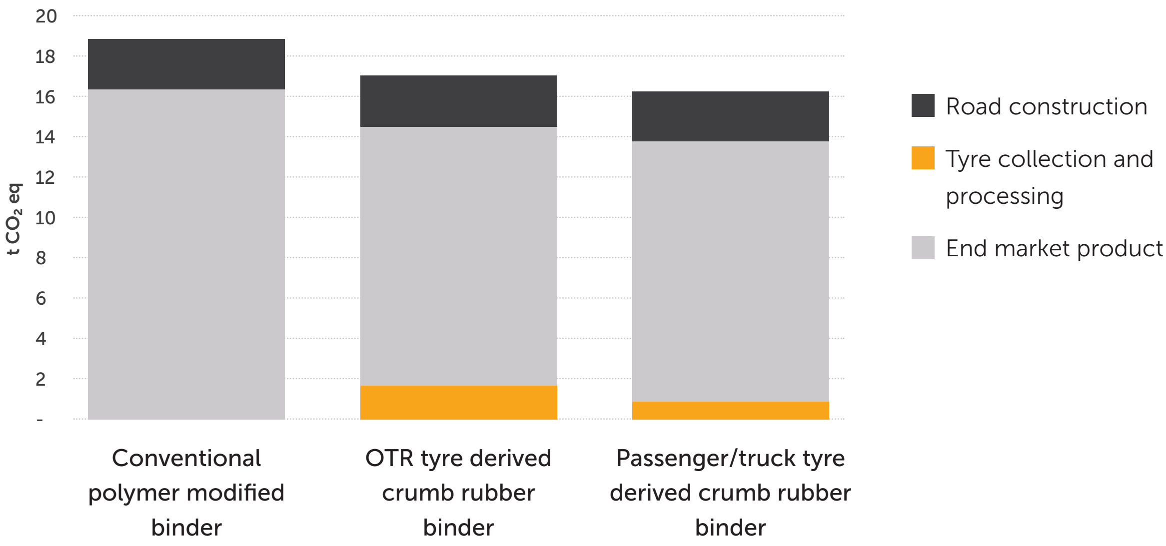


Figure 18: Greenhouse gas emissions from the construction of one km of road, based a crumb rubber asphalt binder mix for an open graded asphalt mix. This is compared to a comparable polymer modified binder mix.

Note: These results have been approximated to an OTR case study based on detailed modelling on passenger and truck tyres. The detailed LCA is presented earlier in the report are a more accurate reflection of the impacts of OTR recovery across different tyre types, locations, and recovery pathways. However, these results are presented here to reflect the potential environmental benefits of OTR recovery.

Appendix 2

Equivalent passenger unit ratios for OTR tyres (TSA, 2019)

Type of OTR tyre	Weight at EOL (kg)	EPU ratio
Solid - Extra small (<0.15 m)	0.84	0.11
Solid - Small (0.15–0.30 m)	24	3
Solid -Medium (0.30–0.45 m)	40	5
Solid - Large (0.45–0.60 m)	56	7
Solid - Extra large (>0.60 m)	72	9
Tractor - Small (<1 m)	120	15
Tractor - Large (>1 m)	200	25
Fork lift - Small (<0.30 m)	16	2
Fork lift - Medium (0.30–0.45 m)	32	4
Fork lift - Large (0.45–0.60 m)	48	6
Grader	120	15
Earth mover - Small (<1 m)	160	20
Earth mover - Medium (1.0–1.5 m)	400	50
Earth mover - Large (1.5–2.0 m)	800	100
Earth mover - Extra large (2.0–3.0 m)	1600	200
Earth mover - Giant (>3 m)	3200	400

References

Corti, A., & Lombardi, L. (2004).
End Life Tyres: Alternative Final Disposal Processes Compared by LCA. Energy, 29, 2089-2018.

DCCEEW. (2023).
Electricity generation. Retrieved from https://www.energy.gov.au/data/electricity-generation

ISO. (2006).
ISO 14040:2006. Environmental management – Life cycle assessment – Principles and framework. Geneva: International Organization for Standardization. https://www.iso.org/standard/37456.html

ISO. (2018).
ISO 14044:2006. Environmental management – Life cycle assessment – Requirements and guidelines. Geneva: International Organization for Standardization. https://www.iso.org/standard/38498.html

Rouwette, B. (2020).
Life Cycle Inventory (LCI) of Secondary Rubber Products. Tyre Stewardship Australia Ltd.

TSA. (2019).
Guildlines for the Tyre Product Stewardship Scheme. Tyre Stewardship Australia Ltd.

TSA. (2020).
Used Tyres Supply Chain and Fate Analysis. Tyre Stewardship Australia Ltd.

TSA. (2023).
Tipping the Balance: The Business Case for a Circular Economy for Australia's Off-the-road Tyres, Conveyors, and Tracks. Tyre Stewardship Australia Ltd.

TSA. (2024).
Life Cycle Assesssment of End-of-Life Tyres. Tyre Stewardship Australia Ltd.

TyreStewardship
AUSTRALIA

Australian Government Accredited Product Stewardship Scheme

TSA0354/08.2024