Mapping Emissions and Waste Stream Profiles and Opportunities for Achieving Net-Zero Circular Advanced Manufacturing

Technical Report

aurecon

thinkstep anz

Sustainable Business Network

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Author(s):	Aurecon, thinkstep-anz and Sustainable Business Network	
Contact:	Aurecon New Zealand Ltd Spark Central Level 8, 42-52 Willis Street Wellington 6011 New Zealand	www.aurecongroup.com wellington@aurecongroup.com +64 4 472 9589
	thinkstep Ltd 11 Rawhiti Road Pukerua Bay Wellington 5026 New Zealand	www.thinkstep-anz.com anz@thinkstep-anz.com +64 4 889 2520
	Sustainable Business Network Darby Building Office 3, Level 2 8 - 18 Darby Street Auckland 1010 New Zealand	www.sustainable.org.nz office@sustainable.org.nz +64 9 826 0394
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Executive summary

1. The aim of this study and what we did

This study supports the growth and resilience of Aotearoa New Zealand's advanced manufacturing sector. The goals were to:

- identify and map the sector's emissions and waste patterns
- find ways to adopt net-zero circular manufacturing practices within and across sub-sectors.

The study supports work underway on New Zealand's Emissions Reduction Plan (Ministry for the Environment, 2022), Circular Economy and Bioeconomy (MBIE, Circular Economy and Bioeconomy, 2024) and Te rautaki para Waste Strategy (Ministry for the Environment, 2023).

Net-zero practices aim to eliminate carbon emissions by cutting them entirely or reducing them to the point where the remaining emissions can be offset. These emissions typically stem from the energy we use and products we consume.

The **Circular Economy** seeks to decouple the economic value of goods and services from the impacts of extraction and waste production by designing out waste, keeping assets and materials at their highest value and regenerating nature. The circular economy is closely linked to the **Bioeconomy,** which uses renewable biological resources to produce food, products, and energy.

We used quantitative and qualitative methods to map emissions and waste across the advanced manufacturing sector and its seven sub-sectors, using data from 2019 (the last pre-Covid year with robust data).

A combination of 'top-down' and 'bottom-up' approaches provided broad and detailed views of the current state of New Zealand's advanced manufacturing sectors and potential opportunities. The project combined desktop research, stakeholder engagement, and reporting.

2. What we found

Circular economy practices exist in New Zealand within and across manufacturing sub-sectors. Sectors differ greatly. However, they are connected through resource flows and face similar challenges, particularly around waste.

Features of New Zealand's national and regional economies, import and export dependencies and manufacturing sector influence opportunities for change, the barriers that limit change and the enablers that support it. (Sections 2.1 and 2.2 below.)

Sector	Features	Emissions hotspots	Waste flows	Opportunities	Data gaps
Food & beverage	• 30.8% manufacturing GDP share ($7.46B) • Strong export market • Significant employer	• Dairy • Meat • Seafood	• Organic waste • Mature co/by-product streams	• Process heat decarbonisation • Food loss reduction	• Waste • Packaging • More granular sub-sector emission factors
Machinery & equipment	• 20.1% manufacturing GDP share ($4.87B) • Heavy import reliance • Enabling sector	• Minimal domestic manufacturing so supply chain emissions offshored	• Scrap currently exported	• Product stewardship • Product as a service • E-waste and vehicle recycling	• More granular sub-sector emission factors • Material stocks and flows • Critical minerals
Wood & paper	• 8.9% manufacturing GDP share ($2.15B) • Biogenic - 7.8% used towards energy	• Bio-energy has minimal emissions, but some facilities still use fossil energy	• Organic waste • Potentially hazardous • Established residue management	• Process heat decarbonisation • Value-add e.g. engineered timber	• Water use • End of life waste • Slash management • More granular sub-sector emission factors
Metal & metal products	• 11.6% manufacturing GDP share ($2.82B) • Significant change underway	• Steel • Aluminium	• Mature internal scrap recycling • End-of-life scrap currently exported	• Electric arc furnace for onshore recycling • Longer-term decarbonisation of virgin metal	• More granular sub-sector emission factors • Non-ferrous metals • Critical minerals
Chemicals & refining	• 11.5% manufacturing GDP share ($2.79B) • Significant change underway • Heavy import reliance	• Petroleum • Methanol • Fertilisers	• Potentially hazardous	• Biorefining • Fleet transition	• More granular sub-sector emission factors • International emission factors
Plastics & rubber	• 4.6% manufacturing GDP share ($1.12B) • Close links to other sub-sectors	• Minimal domestic manufacturing so supply chain emissions offshored	• Problematic plastics • Mature internal plastics recycling	• Design for reduction, recycling and reuse • Product stewardship • Onshore recycling	• Litter and microplastics • Material stocks and flows • More granular sub-sector emission factors
Other manufacturing	• 12.5% manufacturing GDP share ($3.03B) • Diverse • Heavy import reliance	• Cement/concrete • Lime • Glass • Textiles	• Highly variable based on product	• Cement replacement • Recycled aggregates • Product stewardship	• Textile emission factors • Internal market flows • Material stocks and flows

3. Opportunities offered by net-zero circular advanced manufacturing

Risks and costs

- Reduced risks (operational, market, regulatory, portfolio)
- Reduced costs (materials, supply chain, labour, logistics)
- Reduced cost per unit and/or increased productivity (more value from the same inputs)

Supply chain and production

- More resilient supply chains (less reliant on global supply)
- Higher domestic production (consumption of NZ-made products replaces imports)
- Better use of waste as inputs across manufacturing sectors (industrial symbiosis)

Brand and marketing

- Improved brand recognition (due to differentiated products)
- Sustainability credentials that support marketing (e.g. lower carbon products)

Asset management

- Longer asset lives, deferred investment in new assets
- Improved productivity (utilisation, reliability, availability)
- Reduced lifetime operating costs

Relationships

- Social licence to operate
- More skilled jobs (servicing assets rather than replacing them)

4. Barriers and enablers for manufacturers

Barriers

- Access to capital remains a significant hurdle alongside competition within organisations for funding for these projects.
- Businesses often prioritise other challenges over sustainability due to perceived or real risks associated with emerging technologies, processes and business models.
- Initiatives can be complicated by a lack of familiarity with circular business models and insufficient access to necessary supply chains, such as energy and dispersed assets.
- The scarcity of workforce knowledge, skilled staff and intellectual property challenges pose substantial obstacles.

Enablers

- Cross-sector and regional collaboration, alongside sector-specific guidance, helps minimise the technical and commercial risks of adopting ‘higher risk’ solutions.
- Accessible funding/financing is critical to support emerging technologies.
- Government policies and regulations, such as environmental reporting programmes, promote this shift.

- National and industry-specific targets for circularity and supporting innovations in bio-refining and digital technologies help make sustainable practices 'business as usual'.

5. Conclusions

1. Circular economy practices exist within and across New Zealand's different manufacturing sectors. While sub-sectors differ greatly, they are connected through resource flows and face similar challenges, particularly around waste.
2. Supply chain emissions are significant across all sub-sectors.
3. Most sub-sectors depend on imports and 'offshore' their emissions. As a result, some will be exposed to critical minerals risks (e.g. fertilisers, machinery, and equipment).
4. For import-dependent sub-sectors, circular economy models that reduce consumption by extending service lives, sharing access to products or creating jobs through reuse, remanufacturing or repair, may reduce supply risks and global emissions.
5. In some sub-sectors, opportunities exist to use more of what we produce locally. In some cases, this could make businesses more resilient and create skilled jobs. Clear policies on managing domestic versus global emissions need to guide these transitions.
6. Solutions that match companies' business needs (e.g. support market access) are more commercially attractive.
7. The industry is open to collaborating but needs support to overcome transparency and access to better data to support decision-making. This is currently considered a market failure.

6. Recommendations

1. Continue to develop and update the data in this report with industry to understand trends and changes to manufacturing emissions and waste.
2. Collaborate with industry to identify, prioritise, and realise opportunities to develop a decarbonised, circular manufacturing sector, understand resource flows, and investigate opportunities for industrial symbiosis to reduce and divert waste.
3. Support adopting digital tools (e.g. GIS, digital product passports) to help the industry collect and communicate data. This will encourage product stewardship, help the industry track emissions, and support international trade.
4. Investigate ways to make assets last longer (e.g. investment and depreciation levers).
5. Investigate and address data gaps, limitations and assumptions further, including:
    - Consumption-based emissions (including from imported goods)
    - Stocks and flows (e.g. lifespans, durability, replacement scenarios)
    - Identifying critical minerals links and circular economy strategies to improve resilience (link to NZ Critical Minerals List, to be published soon)
    - Waste data (e.g. volumes and flows)
    - 'Potentially hazardous' waste streams.

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1. Project background and scope

The project 'Mapping Emissions and Waste Stream Profiles, and Opportunities for Achieving Net-zero Circular Advanced Manufacturing' aimed to support Aotearoa New Zealand's advanced manufacturing sector's growth, productivity, and resource efficiency.

It was undertaken by a team from Aurecon, thinkstep-anz, and the Sustainable Business Network, selected by the Ministry of Business, Innovation and Employment (MBIE) through a competitive process in July 2023. The project ran from September 2023 to May 2024, with Aurecon leading the consortium.

This work is closely linked with the MBIE research programme *Impacts, Barriers and Enablers for a Circular Economy*, which includes scope for sector-wide approaches to enable low-emission circular advanced manufacturing.

Mapping Emissions and Waste Stream Profiles, and Opportunities for Achieving Net-zero Circular Advanced Manufacturing intends to provide a 'deep-dive' into advanced manufacturing sub-sectors.

The main goal was to identify and map the emissions and waste patterns of the sector and find ways to adopt net-zero circular manufacturing practices. The team employed a range of methods, including research, data collection, stakeholder engagement, and visualisation techniques, aiming to provide a detailed overview of the sector's current state and opportunities. Outputs included a data set workbook, a final report, a summary report, and a presentation.

At project inception, these findings were to support the advanced manufacturing Industry Transformation Plan (AMITP), specifically focusing on creating a sustainable, circular, net-zero emissions sector, as part of Initiative 10. However in December 2023 the AMITP programme ended. This project was then re-scoped to continue research as part of MBIE's industry policy and advanced manufacturing initiatives, including input to New Zealand Emissions Reduction Plans. Additionally, the project fed into MBIE's broader research on the circular economy and bioeconomy (MBIE, 2024), offering insights and data for sector-wide low-emission circular manufacturing strategies.

MBIE has highlighted the importance of collecting initial data on emissions and waste across the advanced manufacturing sector and its seven specific areas. These areas are: food and beverage, machinery and equipment, paper and wood, metal and metal products, chemicals and refining, plastics and rubber, and other manufacturing. The 'other manufacturing' category includes textiles, cement, concrete, furniture, glass, and ceramics. This data is crucial for creating strategies based on evidence within a circular economy framework. These strategies aim to lower emissions, reduce the use of materials, and decrease waste.

Key outcomes from the research aim to:

- Identify key data gaps and recommendations to address.
- Demonstrate the potential value of insights from this data set over time to help inform and support the sector towards net-zero circular advanced manufacturing.

The project takes a step-by-step approach to developing data sets and mapping these sub-sectors.

This method consists of three main stages:

1. Desktop research to establish knowledge
2. Stakeholder engagement to refine and validate initial findings
3. Reporting

Sub-sector mapping explored inherent differences within the advanced manufacturing sector. This included related products, processes, value chains and location information to identify decarbonisation and circular opportunities within and across sub-sectors. It also included those specific to the Māori economy.

This systematic method included both 'top-down' and 'bottom-up' perspectives, to provide both a broad and detailed view of the current state of advanced manufacturing in New Zealand. It ensures a deep understanding of the sector's environmental impact and identifies key areas where New Zealand can move towards zero emissions within a circular economy framework.

2. Introduction

2.1. The circular economy and bioeconomy in New Zealand

The circular economy recognises that the current 'linear' model, in which resources are extracted, refined, manufactured into products, used and disposed of at ever-increasing rates, is highly wasteful. This waste represents a massive loss of economic, environmental and social value. The inherent unsustainability of this traditional linear consumption pattern is increasingly associated with volatile markets, resource nationalism and accelerating environmental degradation. Demand for materials is set to outpace the ability to supply them sustainably or without exacerbating inequity.

The circular economy is based on a branch of 'industrial ecology' – the study of the ways in which industrial systems do and/or should mimic systems in nature. It is often expressed through three key principles: eliminating waste and pollution, circulating products and materials at their highest value and regenerating nature. It incorporates a systemic transition to renewable energy.

The circular economy seeks to substantially decouple the economic value of goods and services from the impacts of extraction and waste production. This is intended to be achieved by keeping products in use for longer, sharing access to the services they provide and maintaining, reusing, refurbishing, remanufacturing, recycling and composting them to recover material value and the value added to those materials through manufacturing.

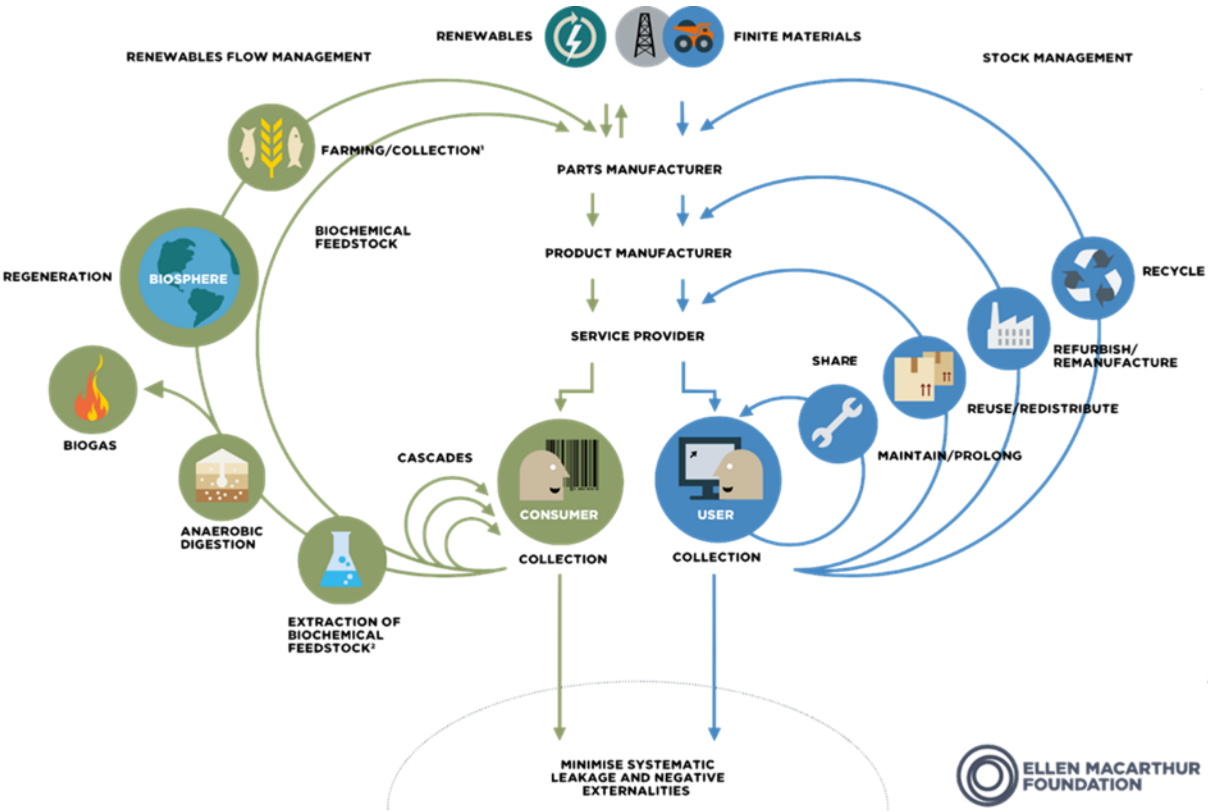

Figure 1 The Ellen MacArthur Foundation 'Butterfly' diagram is a stylised illustration of how value and resources flow in a circular economy.

The circular economy is also closely linked with the 'bioeconomy'. The bioeconomy refers to parts of the economy that use renewable biological resources to produce food, products, and energy. Taken together, they aim for a more sustainable and efficient use of resources. This contributes to environmental goals, like lower emissions and biodiversity protection, as well as seeking to unlock socio-economic advantages such as job creation and economic growth.

2.2. The New Zealand context

The circular economy, like any similar concept, must be adapted to local conditions. For the circular economy, this will require community-and-regional level considerations along with a national perspective and an understanding of, and response to, 'bio-regional' areas defined by ecology and geography.

New Zealand remains a primarily biologically-based economy. The wider food chain (primary, manufacturing, wholesale, retail, food service) directly employs one in five working people in New Zealand.

The economy itself is relatively small. It is distant from major markets and global centres of innovation and knowledge. It has few internationalised firms. These factors mean comparatively higher costs of trade and new market development. They also place limitations on our ability to influence changes in major markets and supply chains.

At a regional level, New Zealand has a relatively small and geographically dispersed population. There is only one global-scale city. This increases the costs of infrastructure development and change, as well as the provision of services such as health care and integrated transport infrastructure.

Each region has different strengths, capabilities and challenges. This means the manner in which they can and will respond to the many different challenges of developing a circular economy will also differ.

The economy is also characterised by a high proportion of small and medium-sized business. These are defined as those with fewer than 20 employees. There are approximately 546,000 small businesses in New Zealand representing 97% of all firms. They account for 29.3% of employment and contribute more than a quarter of New Zealand's gross domestic product (GDP). New Zealand has around 24,000 manufacturing firms that employ more than 239,000 workers (Stats NZ, 2022). This provides special challenges to innovation investment, which is also illustrated by relatively average performance in international innovation indicators.

Some environmental benefits may accrue over long periods. This is particularly the case for service life extension. The benefits may not be felt until the point where the product would have otherwise been replaced. In these cases, the longevity of associated policies and the data required for product assurance and reuse must be carefully considered. The benefits of the system design should be regularly reassessed.

The impacts of circular economy models on developing nations within our supply chains are nuanced. They require a strong focus on the systemic benefits of a circular transition. Many developing regions rely heavily on resource extraction as an economic driver. Developed nations should be mindful of the possible impacts that reducing demand could have. However, given the scale of global markets, it is unlikely that the adoption of circular economy models will result in significant reductions in these exports in the short term.

The impacts of circular economy models also spill over into our supply chains. For example, it is important to be mindful of how our products and systems impact the circularity of the regions that import from New Zealand. It is likely to be important to work collaboratively with key trade partners to ensure that New Zealand products are perceived as durable, high-value goods that support their domestic circular economy targets. Regions such as the UK have already introduced taxes linked to recycled content, and the European Union is introducing digital product passports to capture the sustainability of imported goods for multiple sectors.

New Zealand has a number of related strategy and policy initiatives underway that align with a low-carbon, circular economy transition including NZ's first Emissions Reduction Plan (Ministry for the Environment, 2022), development of a Circular Economy and Bioeconomy Strategy (MBIE, Circular Economy and Bioeconomy, 2024) and NZ's recently updated Te rautaki para Waste Strategy (Ministry for the Environment, 2023).

3. New Zealand manufacturing

This research segments manufacturing activity in New Zealand and related emissions and waste stream profiles by sub-sector, as outlined in Figure 2. There is a particular focus on the top three GPD sub-sectors: food and beverage (30.8%), machinery and equipment (20.1%) and other manufacturing (12.5%). However, all seven sub-sectors have been analysed in detail to develop baseline data sets.

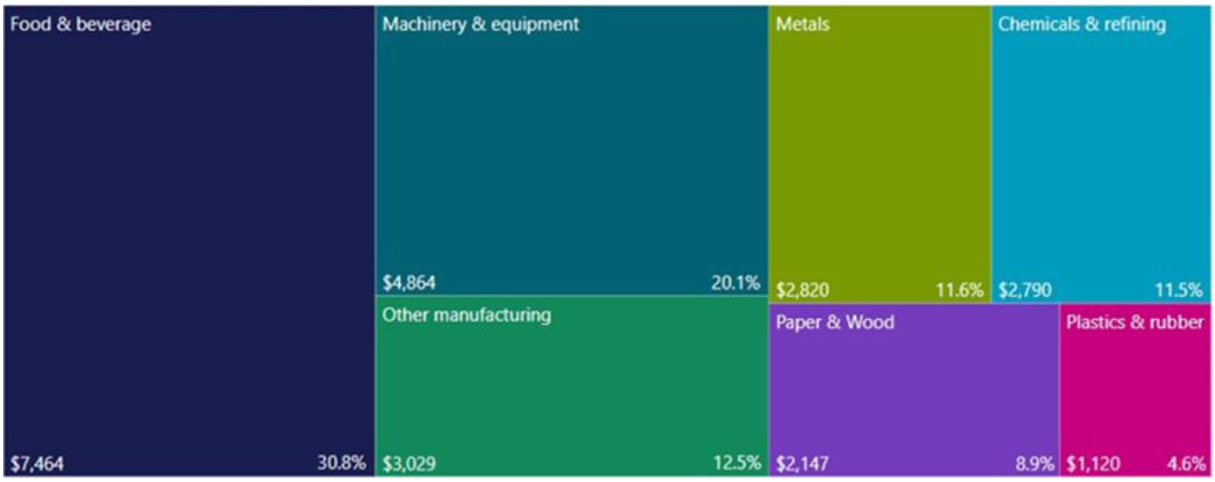

Figure 2 Advanced manufacturing GDP by sub-sector (2020, $millions)

3.1. Unique characteristics of Aotearoa New Zealand manufacturers

While many New Zealand manufacturers adopt processes and technologies used in the same sectors globally, there are several characteristics that make manufacturing in New Zealand unique. These can then then pose different challenges and barriers to decarbonisation and the circular economy that cannot be solved solely from adopting international solutions.

A key difference is that in New Zealand manufacturing is closely linked to the bioeconomy and production of bio-based products.

A working definition within the wider MBIE circular economy research programme describes the bioeconomy in relation to NZ as:

Economic activity involving the use of biotechnology and biomass in the production of goods, services, or energy. In Aotearoa New Zealand, the bioeconomy is a core part of our economy through associated production, processing, services and, ultimately, exports. The bioeconomy is centred on converting renewable biological resources into valuable products, like food and energy. It increasingly uses cutting-edge life sciences to create sustainable alternatives to currently non-renewable resources - a significant growth opportunity for Aotearoa New Zealand.

However, we acknowledge there are varying bioeconomy definitions, and that bioeconomy strategy development is underway by MBIE and MPI, so this may evolve in the future. Regardless, production and processing are the two important parts of the bioeconomy, with manufacturing delivering both early stage and value-add processing capabilities (Coriolis, 2023).

New Zealand's manufacturing sector is largely driven by agriculture - dairy, meat, food and beverage and forestry. This contrasts with the European Union (EU, 2023) and USA (NAM, 2022), for example. Their manufacturing is concentrated in sub-sectors such as chemicals, materials, metals and machinery and equipment. Australia, meanwhile, has strong export markets in minerals and fuels (Department of Foreign Affairs and Trade, 2021). This leads to different assets with different needs.

For example, in New Zealand, there is likely to be a greater consideration of:

- Seasonality of production (e.g. milking seasons, crops) and consequent lower asset utilisation.
- Localised supply chains, where raw ingredients are produced within New Zealand.
- Cold chains and product shelf life.
- Distance from export markets and transport/supply chain implications.
- Heavy reliance on Asian export markets (Figure 3).

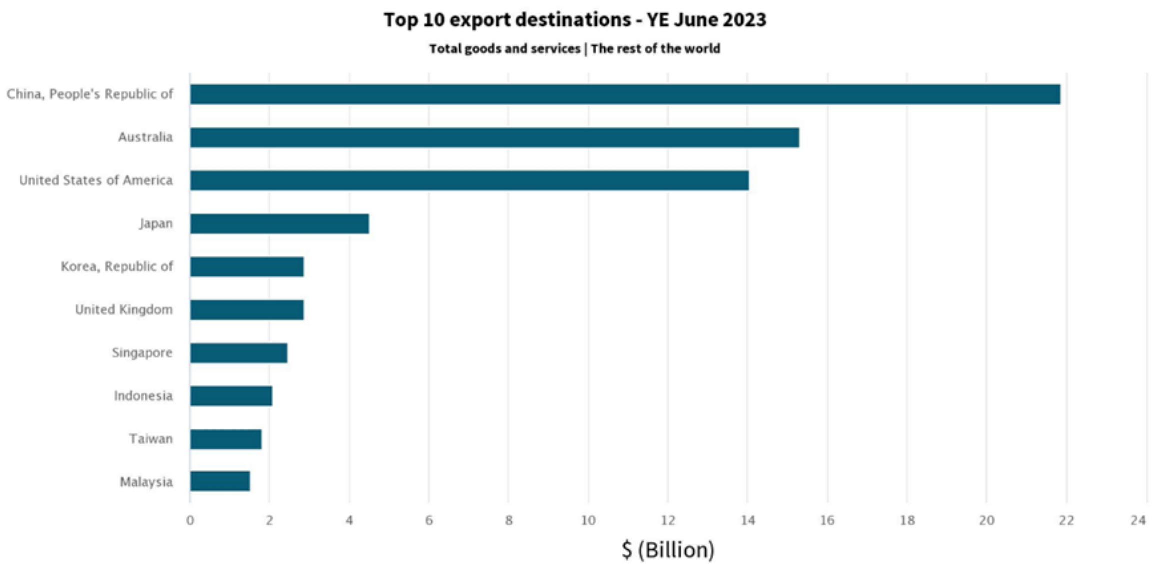

Figure 3 Top 10 export destinations, total goods and services - year ending June 2023 (Stats NZ, 2023)

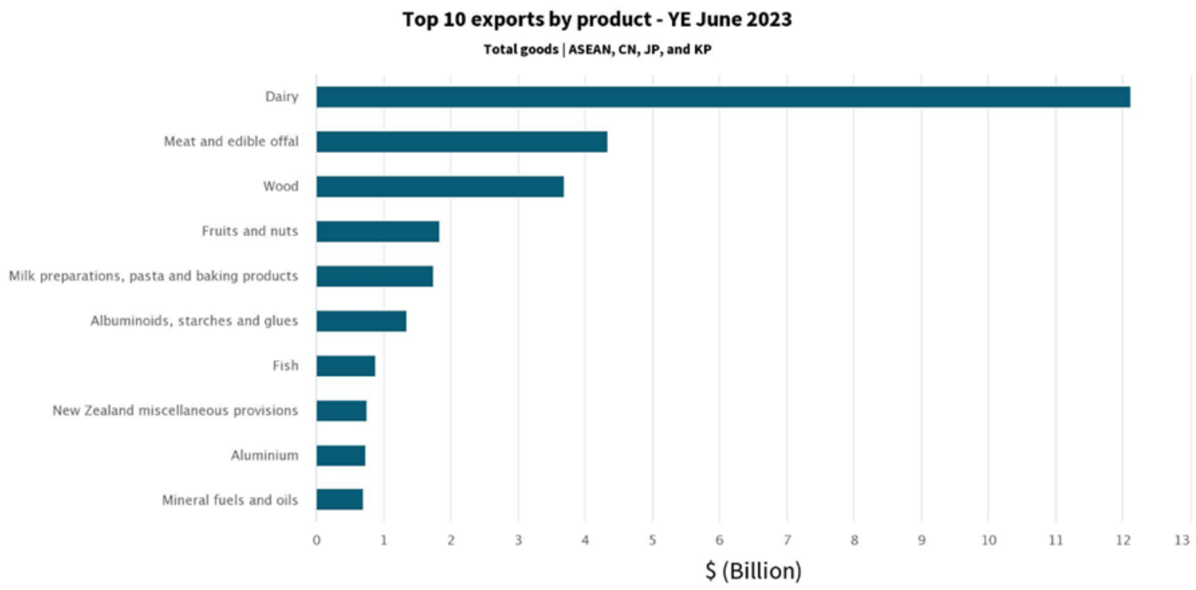

Figure 4 Top 10 NZ exports to countries in Asia – year ending June 2023 (Stats NZ, 2023)

Outside of the agricultural sector and other food and beverage manufacturing, New Zealand also has large-scale resource processing capability, for example in steel and aluminium. In these areas, large businesses such as NZ Steel and the NZ Aluminium Smelter (NZAS) operate as part of larger global companies (i.e. Bluescope and Rio Tinto, respectively). This means that decarbonisation, circular economy and other sustainability ambitions are heavily influenced by global strategy, policy, and markets.

Another aspect to consider is that these large global companies operate a portfolio of assets across the world. This may influence how they choose to decarbonise or enable circularity of their operations in New Zealand. This is especially true where local plants are already running on New Zealand's highly renewable electricity. In some respects this adds to the brand value of the manufactured product. For example, NZAS has its metal marketed under Rio Tinto's RenewAl brand, which certifies NZAS metal as being some of the lowest carbon in the world (Rio Tinto, 2023). This is a potential brand building opportunity that other manufacturers can take advantage of as they shift from fossil fuels to renewable energy resources.

Another characteristic of New Zealand's manufacturing sector is that while there are several large manufacturers at play, there are also many small and medium enterprises (SMEs). SMEs have their own drivers, opportunities and barriers with respect to decarbonisation and circular economy. SMEs may tend to adopt a more entrepreneurial and innovation mindset. For example, Fabrum is pushing forward with green hydrogen and low-carbon materials. However, SMEs may also face barriers such as access to international markets and not being able to apply advanced manufacturing at scale (Fabrum, 2023).

In recognition of the different challenges SMEs might face in decarbonising, Energy Efficiency and Conservation Authority (EECA) launched the Sector Decarbonisation Programme (EECA, Sector Decarbonisation Programme, 2023). This provides sector-specific advice, particularly for smaller businesses that may not have the capacity, capability or financial resources to undergo comprehensive decarbonisation studies.

3.2. Recent trends

The economic and political landscape that manufacturers have been operating in over the past few years has also changed significantly. These changes have not necessarily flowed through to official data.

For example, COVID-19 and global conflicts have resulted in challenges. These include operational losses that some businesses are still recovering from, supply chain disruptions, cost escalation and economic inflationary pressures. There is also still uncertainty for some on what the post-pandemic 'new normal' might look like.

Over that same period, New Zealand has also seen new solutions to support decarbonisation of industry. As part of the COVID-19 economic recovery, the New Zealand Government introduced the Government Investment in Decarbonising Industry (GIDI) Fund. This has supported the deployment of 81 industrial projects, through government co-investment of $112.2 million and $195.9 million in private funding (EECA, 2023). It is important to note that although the GIDI fund has been discontinued, implementation of approved manufacturing initiatives will continue as these are commissioned and go live.

Other funding/financing solutions have also emerged. These include the NZ Green Investment Finance's Green Finance Accelerator (NZGIF, 2023). This focuses on funding for SMEs to accelerate decarbonisation. Major banks across NZ have also begun to offer sustainability-linked loans. For example, Genesis Energy and NZGIF have partnered to pilot a lease model to displace gas-fired boilers. Genesis and NZGIF will provide the heat pump to Van Lier Nurseries on a lease-to-own arrangement, enabling Van Lier Nurseries to spread the cost of the heat pump while receiving engineering and maintenance support from Genesis (Genesis, 2023). Other examples in the market are likely to exist that represent opportunities for manufacturers to pursue.

3.3. Māori manufacturing

Māori are an integral part of the manufacturing sector and New Zealand's economy. The guide to our research has been the He Waka Taurua framework (Maxwell, Ratana, Davies, Taiapa, & Awatere, 2020). This framework helped to inform a way forward to align western approaches to circular economy with te ao Māori principles, perspectives, insights and influence. The goal was to not view the two approaches to circular economy in isolation, but understand the connections and collaborative opportunities available within the advanced manufacturing sector between Māori businesses and other industry representatives regarding circular economy.

A key challenge of this investigation was ensuring that the research is culturally reflective of Māori businesses and considers the values and contributions of te ao Māori principles within the work being undertaken by Māori businesses. Emerging findings and assumptions need to be investigated further, directly with Māori businesses, or they cannot be validated.

3.4. Net-zero circular advanced manufacturing

This project was established to complete phase one of AMITP's Initiative ten towards understanding, at a granular level, the advanced manufacturing sector's emissions and waste profiles, and opportunities and barriers for reduction, to inform ITP actions and initiatives (MBIE, Advanced Manufacturing Industry Transformation Plan, 2023). In year two this information was to be used as a baseline to help develop, measure and inform action with further plans to review and update over time with industry.

Although the AMITP has ended, baseline research to understand manufacturing emissions and waste streams is relevant to numerous work areas within government.

These include:

- Emissions Reduction Plan strategy development (Ministry for the Environment, 2022)
- MfE's Te rautaki para Waste Strategy and waste data programme (Ministry for the Environment, 2023)
- EECA sector decarbonisation programme (Energy Efficiency Conservation Authority, 2024); MBIE Industry Policy (MBIE, 2021)
- Minister of Small Business and Manufacturing portfolio (Beehive, 2023)
- MBIE Circular economy and bioeconomy work programme (MBIE, 2024)
- MPI Policy and Trade programme (MPI, 2024)
- The Parliamentary Commissioner for the Environment's work on resource use in New Zealand (McCarthy, 2024).

We have received strong interest in and support for this work from individual manufacturing businesses and industry bodies including Employers and Manufacturers Association, Plastics NZ, Metals NZ and waste peak industry body WasteMINZ's resource recovery and product stewardship working groups.

Net-zero manufacturing is ambitious. It will require considerable investment to achieve over time. As such, business transition drivers need to be identified and leveraged, with value and asset cycles considered two key opportunities for policymakers and industry to harness.

3.5. Decarbonisation

Decarbonisation of manufacturing in New Zealand has had a large focus in recent years. This has been primarily driven by the sector's energy emissions and the country's need to comply with the Paris Agreement and Climate Change Response Act, alongside policies such as the Emissions Reduction Plan (Ministry for the Environment, 2022) and National Direction for Greenhouse Gas Emissions from Industrial Process Heat (Ministry for the Environment, 2023).

Through programmes such as the Energy Efficiency and Conservation Authority's (EECA) Energy Transition Accelerator and business led initiatives, many of the larger energy users have now completed energy transition plans. They are starting to implement energy efficiency solutions and are switching fuel use away from fossil fuels to renewables (EECA, 2023). Fonterra, as an example, has decreased its Scope 1 and 2 manufacturing emissions by 14% from FY18 to FY23 (Fonterra, Sustainability Report, 2023).

3.6. The circular economy

The circular economy involves a shift from our current traditional, linear, 'take, make, dispose' model of an economy to a ‘closed loop’ system. Waste and pollution are designed out. Materials and products are kept circulating at the highest value possible. Natural systems are regenerated through a combination of reduced resource pressure, environmentally positive production processes and direct intervention in the form of restorative work on landscapes, waterways, and oceans. Assets, products, materials, and resources are designed for durability and extended lifespans. This, combined with the way they are distributed and redistributed, conserves their inherent value, and eliminates both the generation of waste and the concept of waste itself.

Features of this approach include repurposing and recycling used materials and products back into the production cycle, stimulating innovation, new employment opportunities and greater economic resilience.

Manufacturing plays a significant role transforming resources and is the conduit between outputs from one process becoming inputs for the next.

The ‘*Barriers, enablers and approaches for a more circular economy*’ research project (part of the MBIE research programme *Impacts, Barriers and Enablers for a Circular Economy* and linked to this research) undertaken by The Connective, ARUP and Project: Moonshot, found that the biggest opportunity for New Zealand's manufacturing is to leverage our significant primary sector, substituting unsustainable and high embodied carbon materials with renewable ones like timber (see Section 12.2 Additional Associated Research). Equally, there are opportunities to localise supply chains and secure critical raw materials (CRM) and component parts for New Zealand’s emerging clean tech sector. Accelerating existing transition metal recovery efforts and building regional relationships with stable trading partners will enable this.

3.7. Potential business value of net-zero circular solutions

Co-benefits can include:

- Reducing costs/improve profitability - energy, operational expenses, capital spend (e.g. through extending asset life)
- Unlocking new value streams – added value, new product or revenue streams
- Improve efficiency - more value from same raw inputs (e.g. waste upcycling/energy recovery)
- Reducing risks - operational risk, market risk, supply chain/logistics
- License to operate - Improve environmental compliance, sustainability or other licence to operate objectives.

3.8. Consideration of asset base and cycles

To meet the pace and scale of the transition, we also need to think about how we transition our legacy assets. Much of the current industry focus is on breakthrough technologies that make up a small proportion of New Zealand's manufacturing asset base. However, New Zealand has billions of dollars of legacy assets on the ground. How can we use the asset lifecycle to bring our legacy assets into the transition to a net-zero circular economy?

The best time to consider net-zero circular economy is arguably at end of asset life when an investment decision needs to be made. At this point, the assets have had their return on investment. The next best time to consider asset replacement is mid-life – broadly 15 to 25 years old depending on what the asset is. Here, replacements may be harder to get across the line because assets still need to earn their return on investment.

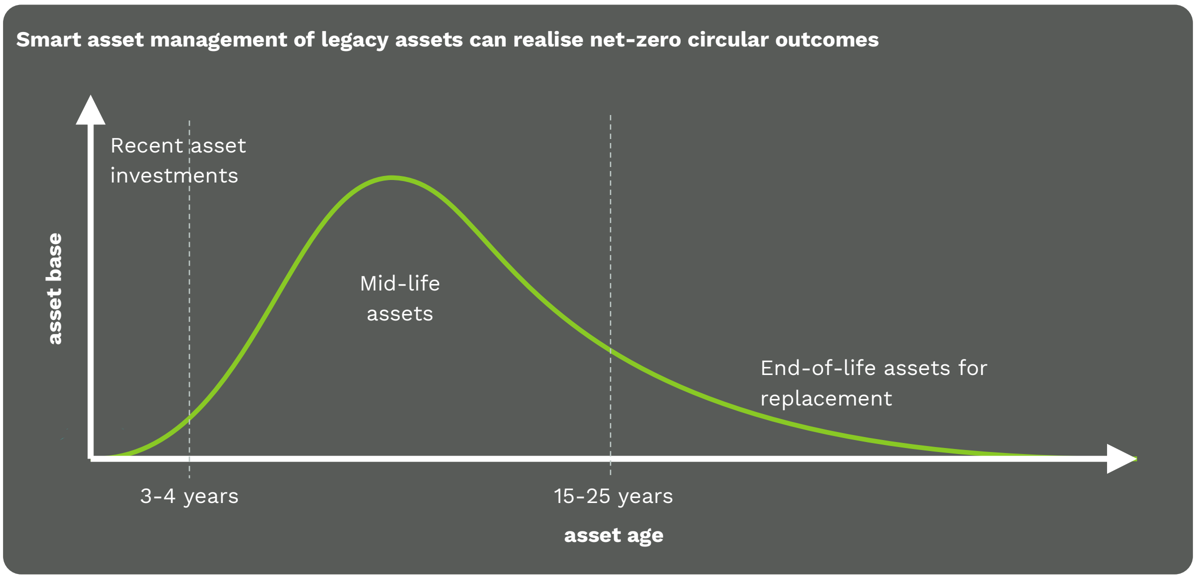

Figure 5 Indicative distribution of recent, mid-life and end-of-life asset base versus age to consider replacement decision-making

The replacement of newly installed assets will be even harder to justify. However, it is likely that net-zero circular economy considerations may have already been considered in their procurement. Regardless, it may be another 15 years before their net-zero outcome can be fully addressed.

This highlights the importance of considering the net-zero circular economy across asset management strategy, not just in innovative breakthrough projects. New Zealand's legacy assets need to be considered as well to meet the pace and scale of the transition required.

4. Manufacturing sector mapping

In this section we will provide a top-line sector-wide assessment of waste and emissions mapping, with further interrogation by sub-sector in later sections.

MBIE has indicatively split the advanced manufacturing sector into seven constituent sub-sectors (Table 1) as per Australian and New Zealand Standard Industrial Classification (ANZSIC), including granularity to ANZSIC levels 3 and 4 where required to effectively link sectors to product outputs.

Developing baseline emissions and waste flows for New Zealand manufacturing at a granular level is central to this project, with a range of qualitative and quantitative approaches applied to profile or 'map' each sub-sector. Early-stage desktop research looked for existing data sources at national, regional, and business and facility levels to understand waste and emissions data within the manufacturing context. Due to data quality and availability, including challenges during the COVID-19 period, 2019 was selected as the base year, with the intent that the data set would be updated over time. 2024 is expected to be the next period with robust economic data availability.

The overall mapping process was highly iterative and helped us build a more accurate picture of the current state, knowledge gaps and interdependencies. Considerations also included manufacturing processes and activity location. Sub-sector-specific data is valuable as it informs decisions at different scales and levels, prioritises transition activities and measures progress over time. Although we are primarily interested in what is made in New Zealand, inclusion of both production-and-consumption related emissions was important, highlighting imports and exports and the role international trade plays.

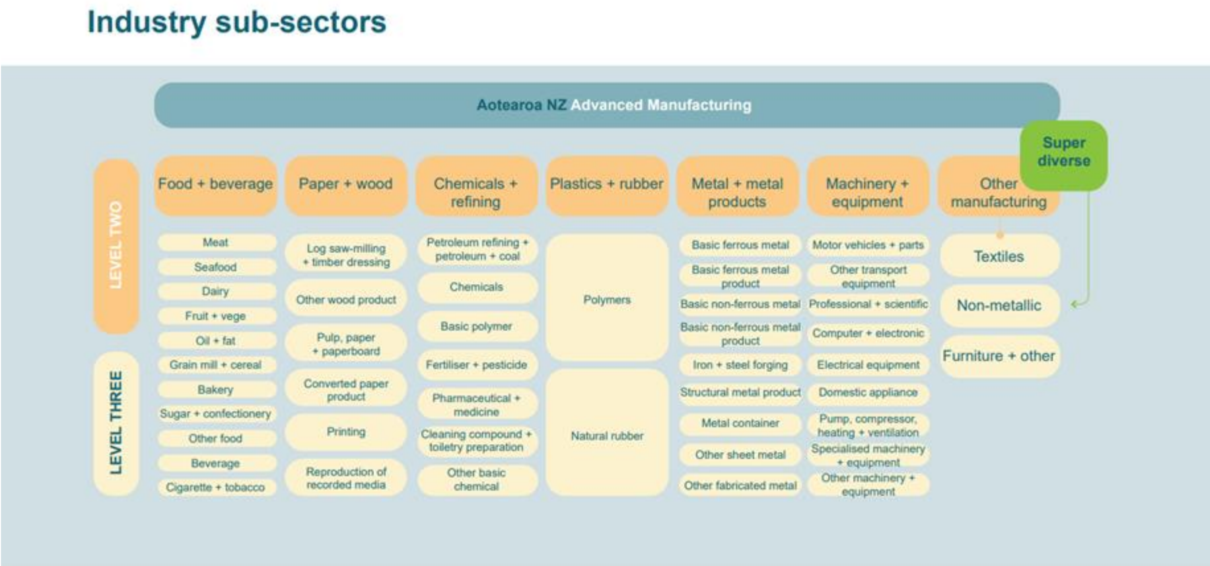

Figure 6 Overview of manufacturing ANZSIC Level 2 sectors and Level 3 sub-sectors

Table 1 Advanced manufacturing sub-sectors, ANZSIC counterparts and example firms

Manufacturing sectors	ANZSIC level 2	Example firms
Food & beverage	C11 – Food Product Manufacturing C12 – Beverage & Tobacco Product Manufacturing	Fonterra; Sanford; ANZCO; Mudhouse Wines; DB Breweries; Whittaker's; Tasti; Tegel; Frucor; Miraka; Hellers; Vitaco; Heinz Watties; McCains; Kaweka Foods
Machinery & equipment	C23 – Transport Equipment Manufacturing C24 – Machinery & Equipment Manufacturing	Fisher & Paykel Healthcare; Compac Sorting; Buckley Systems; Gallagher Security; Tait Communications; Moffat; Skope Industries; Scott Technology; Trimax Mowing Systems; Southern Spars
Wood & paper	C14 – Wood Product Manufacturing C15 – Pulp, Paper, and Converted Paper Product Manufacturing C16 – Printing	Sequal; Tenon; Nelson Pine; Juken New Zealand; Red Stag Timber; Xlam; Kinleith Pulp and Paper Mill (Oji Fibre Solutions); Tasman Pulp and Paper Mill (pulp mill owned by Oji Fibre Solutions, paper mill owned by Norske Skog Tasman)
Metal & metal Products	C21 – Primary Metal and Metal Product Manufacturing C22 – Fabricated Metal Product Manufacturing	New Zealand Steel; Fletcher Steel; New Zealand Aluminium Smelters; Steel and Tube; Ulrich Aluminium
Chemicals & refining	C17 – Petroleum and Coal Product Manufacturing C18 – Basic Chemicals and Chemical Product Manufacturing	Nuplex; Douglas Pharmaceuticals; New Zealand Pharmaceuticals; Trilogy (cosmetics); Ravensdown Fertiliser; Dulux; Resene
Plastics & rubber	C19 – Polymer Product and Rubber Product Manufacturing	Sistema; Alto Packaging; Axiam Plastics Ltd; Blender Design Ltd; Dynex Extrusions Ltd; Talbot Technologies; Skellerup Industries; Field Rubber; Rubber Developments
Other Manufacturing	C13 – Textile, Leather, Clothing and Footwear Manufacturing C20 – Non-Metallic Mineral Product Manufacturing C25 – Furniture and Other Manufacturing	Firth Industries; Bremworth; NZ Comfort Group (Sleepyhead); Blunt Umbrellas; Noho; Alliance Printers

4.1. Emissions mapping

There are two ways we look at emissions in this report, and they treat two things differently: supply chain (or indirect) emissions, and international trade. The first, **production emissions,** are those directly emitted by manufacturers within New Zealand and include anything we produce, regardless of whether we then consume it ourselves or export it elsewhere. Production emissions exclude indirect and supply chain emissions. **Consumption emissions** are associated with the goods and services New Zealand consumes, including their indirect and supply chain emissions. This includes what we produce for our own consumption, and what we import and consume associated with the production emissions of other countries.

In terms of NZ manufacturing emissions, the top-down GHG emissions account shows that most advanced manufacturing sub-sectors have significantly higher consumption-based emissions compared to production-based emissions (Figure 7).

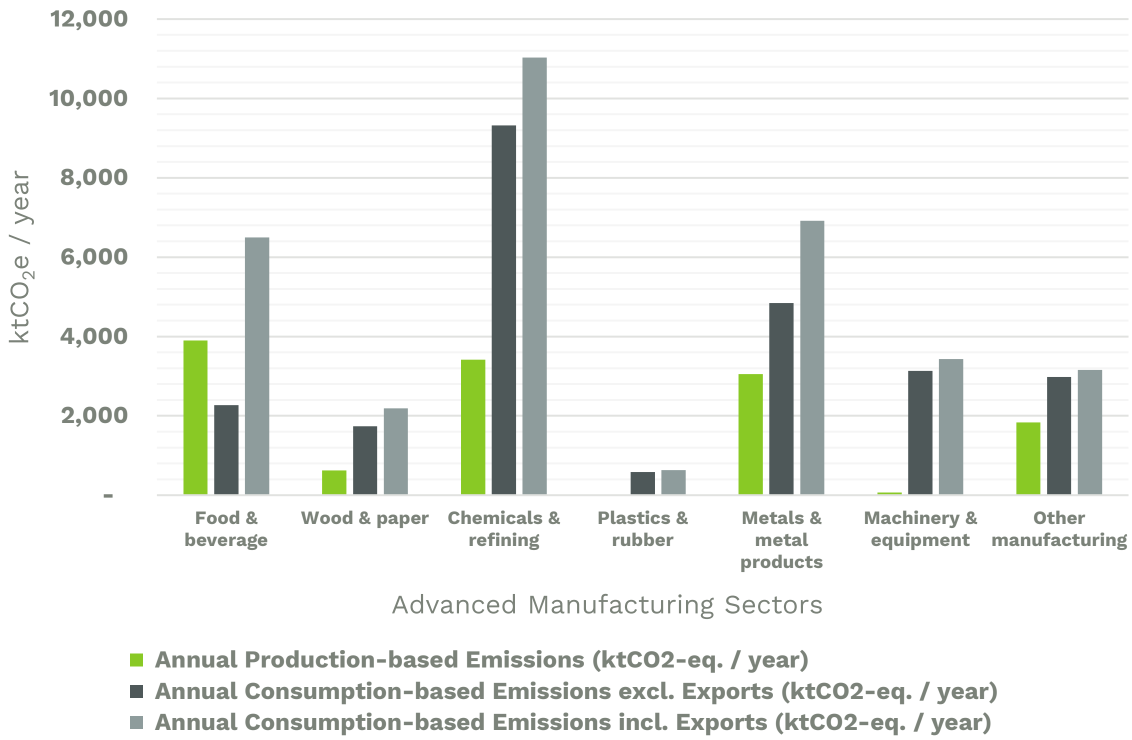

Figure 7 GWP (ktCO$_2$e) impacts of production versus consumption-based (production + supply chain) perspectives, both including and excluding exported goods – 2019 baseline

The assessment methodology uses domestic production emissions as a proxy for international production, which may lead to some variations in the results. For example, in metals and metal product manufacturing, domestically produced aluminium is expected to have lower carbon emissions compared to imported stock due to NZ's renewable electricity sources (Rio Tinto, 2023). On the other hand, domestic steel production likely has a higher emissions intensity than imported products, highlighting the variability by product type.

The higher magnitude of consumption-based emissions suggests that NZ relies heavily on imports for many manufacturing sub-sectors. This analysis can help identify opportunities for local production with lower emissions to replace imported inputs and goods. A sensitivity analysis in Section 12 of the report examines the impact of international emissions intensities on consumption-based emissions.

One exception to the trend is the food and beverage industry, particularly dairy production, which is a major sector of NZ's economy and involves significant exports to countries like China. Even when accounting for supply chain emissions, the consumption-based emissions for this sector are still lower than the production-based emissions due to the volume of dairy and meat exports.

The dominance of supply chain emissions provides insights into potential emissions reductions within these industries. Implementing circular economy initiatives to utilise by-products and co-products across industries can help reduce the overall emissions footprint, especially considering that many input materials are imported. Finding alternative sources within NZ could reduce supply chain emissions and increase resilience to global supply chain disruptions. It is important to note that circular economies are often region-specific, and not all advanced manufacturing industries operate in the same locations.

Production-based emissions, on the other hand, predominantly depend on the type and amount of energy used for processing. Figure 8 suggests that chemicals and metals have relatively large production-based emissions footprints, possibly due to the widespread use of coal and natural gas in their operations. Reducing production-based emissions poses challenges such as the need for significant increases in electricity generation capacity to enable electrification or developing alternative fuel and feedstock supply chains.

There is interdependence between many of these industries, meaning that emission reductions in one industry can have ripple effects on others. For instance, the food and beverage sector's consumption-based emissions rely on the agriculture and horticulture sector, as well as the chemicals industry for fertilizers. These interdependencies and resource flows are shown in more detail through the sub-sector mapping, waste flows, and bottom-up emissions accounts.

When normalising the figures for the revenues of these industries, we can see the emissions footprint per dollar – providing a fairer comparison of marginal emissions. Note that spend in one sector becomes revenue in another, and that the difference in terminology here comes from shifts in perspective, rather than different values.

We see two clear standouts: chemicals and fuel refining, and metals (Figure 8). This could indicate that these industries emit much more than others for each dollar spent within these industries, especially when accounting for their supply chains.

It is important to note that data presented here has a baseline of 2019 and does not account for the closure of the Marsden Point refinery in 2022, suggesting that consumption emissions would likely be higher and production emissions lower if this data was to be updated at the present time.

Additionally, the production-based emissions data from Stats NZ do not align with the data formats used for consumption modelling. Aggregation, concordance management and documentation are required. To scale data beyond 2020 (the final year of data from the NZ emissions inventory under the Kyoto Protocol), a less robust, estimate-based methodology would need to be employed.

A potential insight from the emissions intensities data as shown in Figure 8 is that growth in some industries would result in a disproportionately large increase in total production- and consumption-based emissions. This suggests that in some cases, a strategy to lower the emissions impact of a given industry in NZ would be to reduce local manufacturing capacity and import products, rather than manufacture them locally with less efficient or more emissions-intensive technologies and processes. This assumption is tested for some sample sub-sectors through sensitivity analysis (Section 13, Sensitivity analysis) utilising representative emissions intensities for key imported product sectors.

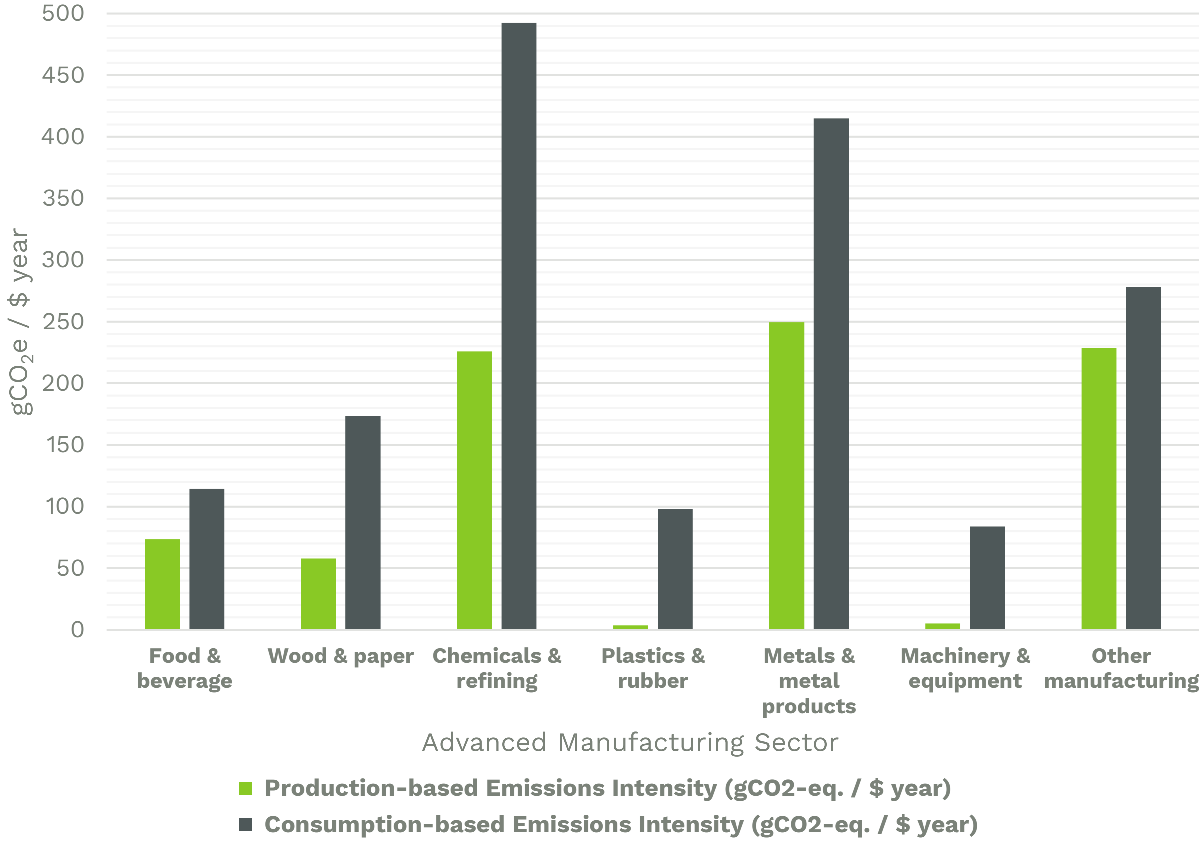

Figure 8: Weighted average production- and consumption-based emissions intensities of the advanced manufacturing sector – 2019 baseline

A weighted average of the ANZSIC06 sub-sectors that make up these aggregated categories is used for this top-line analysis. This addresses data where sub-sectors have a large variance (e.g. in the food and beverage sector, meat and dairy are much larger than other sub-sectors in both value and emissions).

We see that accounting for the production of goods bound for export in the consumption-based emission figures makes a significant difference (Figure 8). For the food and beverage sector, when including products bound for export, the sector's consumption-based emissions are larger than production-based emissions alone, due to the inclusion of supply chain emissions. Furthermore, for export-driven sectors, the emissions of these exported products are higher than those of domestically consumed products (including imports). While these figures are not, by definition, consumption-based emissions, they provide a more "apples-to-apples" comparison with production-based figures. This is explored in more detail in the food and beverage section.

Taking a regional perspective, a heatmap of production-based emissions reveals territories with higher emissions (Figure 9). Auckland, Whangārei, Christchurch, and Wellington emerge as the largest sources of emissions, likely due to employment numbers and being manufacturing centres. Mid-range regions include Southland, the West Coast, and the Waikato, while low-emissions regions include Central Otago, Taranaki, and Thames-Coromandel. The consumption-based emissions heatmap mirrors the production-based one, as the changes in emission numbers are proportional.

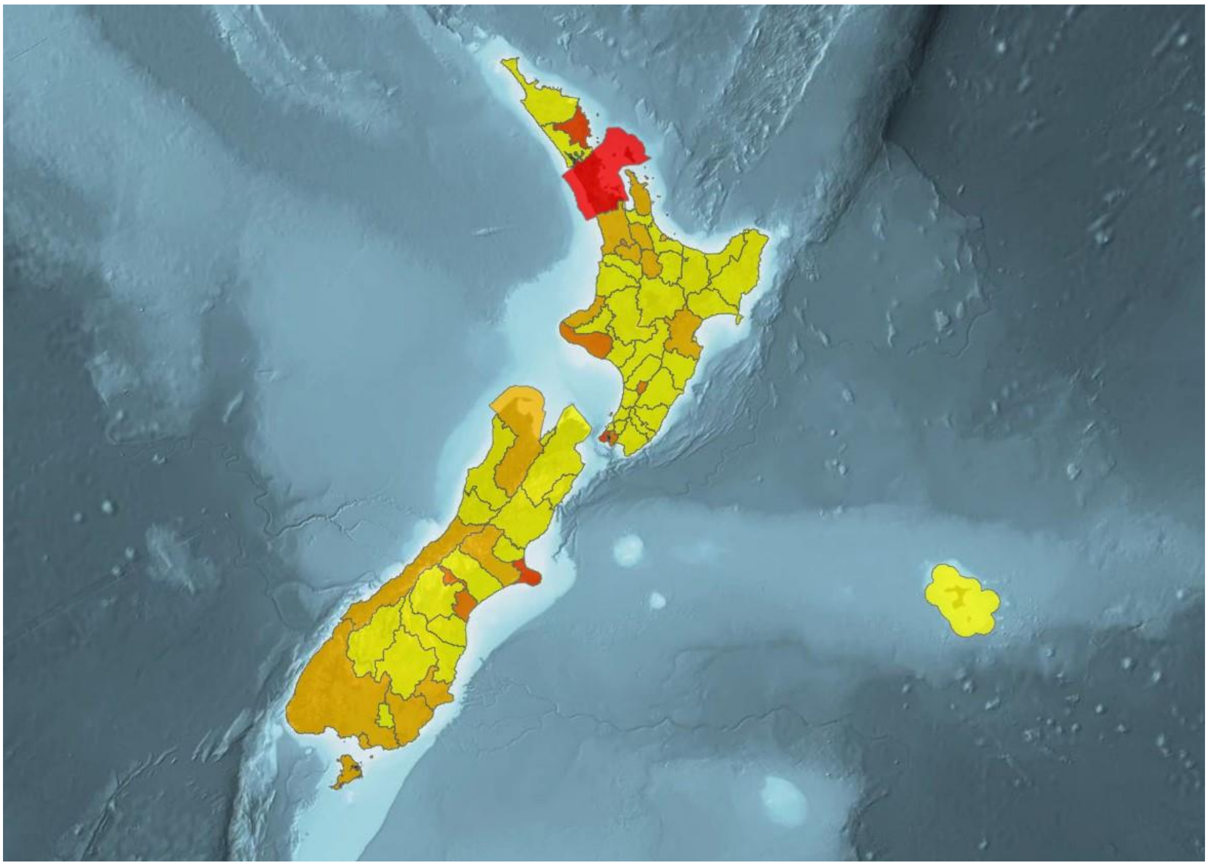

Figure 9 Heatmap of production-based emissions by territorial authority - 2019 baseline

With Auckland, Christchurch and Wellington representing New Zealand's largest population centres, the employment number-based approach may skew results, though these emissions are also expected to be large manufacturing centres. Whangārei differs from these, with a much lower population, but is the location of Marsden Point refinery, which at the point of this baseline (2019) was still active. With chemicals and refining being the largest emissions contributor, we expected Whangārei to be a significant emissions hotspot for the manufacturing sector. This will have changed by the time of writing this report, with the closure of Marsden Point refinery in April 2022.

The total consumption-based emissions of NZ's manufacturing sector, as determined by the top-down method, amount to 24,871 $ktCO_2e$. per year for the 2019 baseline. The equivalent total from Stats NZ, where only sector totals are provided, is 23,272 $ktCO_2e$. per year, showing a 6.4% difference. This discrepancy is likely due to the estimation of domestic production numbers for primary ferrous and non-ferrous materials and the inclusion of estimated supply chain emissions for certain auxiliary finance services where data was lacking in Stats NZ production-based emissions (NZSIOC). Note the Stats NZ consumption account uses the residency accounting principle, while the presented top-down account uses the territory principle. This will contribute to this difference. In the residency approach, all contributions from NZ residents are considered, whether emissions occur domestically or over overseas. With the territory approach, all NZ residents and non-NZ residents' contributions are considered, if they occur domestically in NZ territory. The top-down production-based emissions total is 12,913 $ktCO_2e$. per year, roughly half of the consumption-based total. This indicates that the overall NZ advanced manufacturing sector's consumption-based emissions footprint, is roughly double the domestic production (energy and direct emissions) account. Importantly, these figures exclude consumption emissions from end-use products like aerosols in cosmetics and refrigerant leakage from household heat pumps, which are accounted for separately in the Stats NZ production-based emissions inventory via 'household' categories. In the production account, these categories account for 11.7% of the total footprint. These have not been allocated to the total due to difficulty in attributing these emissions back to ANZSIC06 sub-sectors, and their not being as relevant to circular economy opportunities for the manufacturing sector. Overall, the production-based total for manufacturing is 15.48% of NZ's total emissions in 2019 (excluding household direct emissions). Using Stats NZ's consumption accounts, and noting the methodological differences, the top-down approach accounts for 38.33% of NZ's 2019 total on a consumption basis.

The initial scope for this top-down analysis included mapping the sector's emissions to ISO 14064 categories. However, through the development process, it was determined that it was not appropriate for this exercise. This type of categorisation where emissions are assigned 'scopes' is typically used in commercial emissions inventories where there is a clear distinction between emissions owned by the company, and those relevant to the value chain. However, applying sweeping assumptions to an entire industry with varying levels of vertical integration would not yield meaningful insights in this context. A simplified approach for allocating emissions to scopes was created based on high-level assumptions, but this method was not applied in the final data analysis.

4.2. Waste mapping

In general, publicly available data on waste in New Zealand is limited. It varies in consistency and quality, which impacts its usability for application to sectors such as advanced manufacturing.

Currently, the most consistent source of waste data is through waste disposal levy reporting managed by MfE. This programme has been collecting Class 1 landfill disposal and diversion data by tonnage since 2009. Class 2 to 5 landfills were included from 2021 and inaugural reporting is expected in 2024.

Although it is useful to understand the material composition entering landfill and diversion information at this point, it is difficult to link material types and volumes to source such as manufacturing. We also acknowledge the integral role advanced manufacturing has in resource recovery and value add.

At present, waste inputs into the system from diversion activities are not well captured. However, through this project we have attempted to capture top-town waste and recycling flows as per Figure 10.

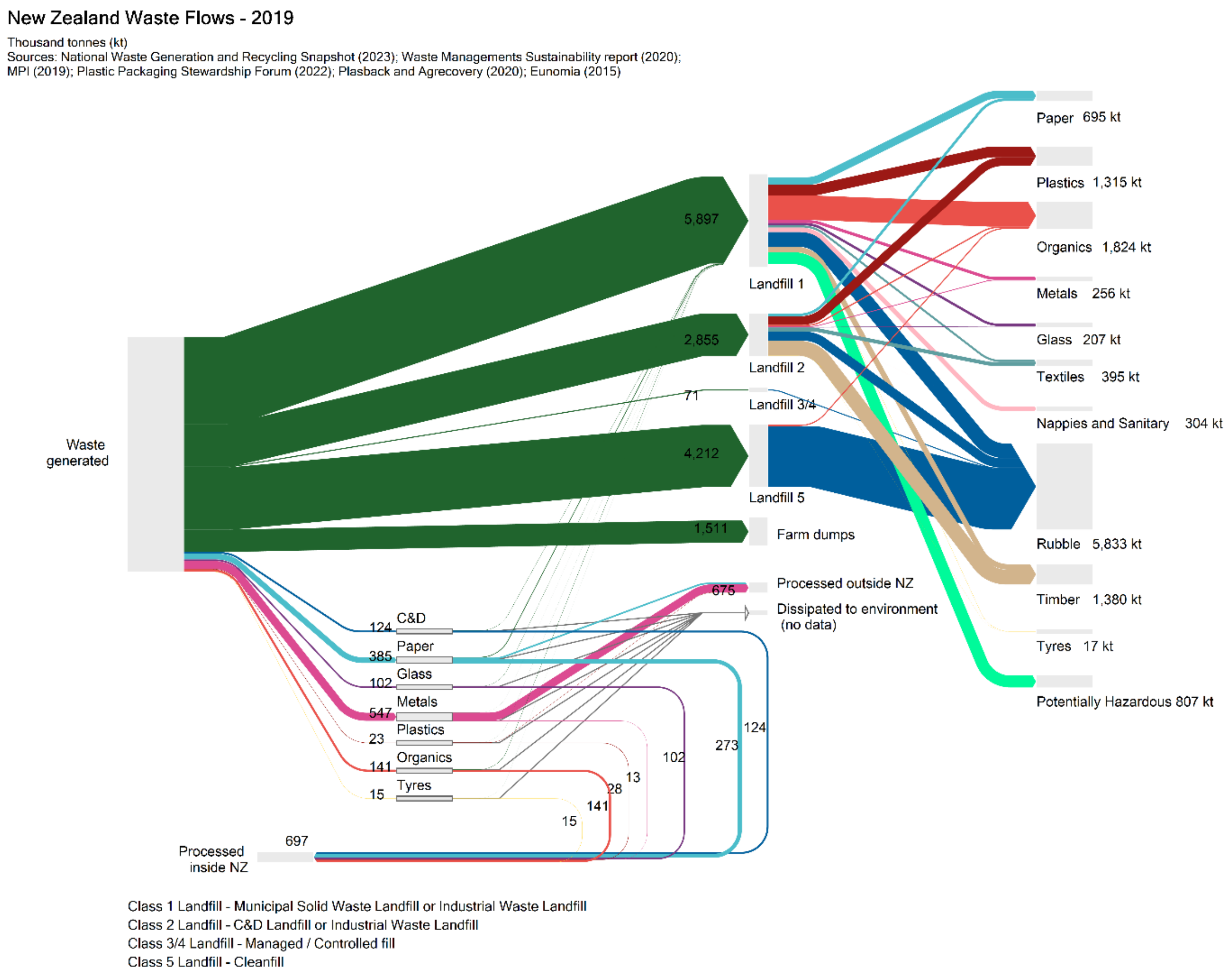

Figure 10 NZ waste flows and material composition- 2019

Key observations from Figure 10 include:

- Of the 17,288 kt of waste generated by New Zealand in 2019, the majority (92%) ended up in landfill. This comprised 5,897 kt (34%) to Class 1 landfill, 2,855 kt (16.5%) to Class 2 landfill, 71 kt (0.4%) to Class 3 landfill, 4,212 kt (24%) to Class 4 landfill and 1,511 kt (9%) to farm dumps.
- Of the remaining 1,371 kt (8%) of waste that was either recycled or exported, this comprised 124 kt (9%) construction and demolition waste, 385 kt (28%) Cardboard and paper, 102 kt (7%) glass, 560 kt (41%) metal, 43 kt (3%) plastics, 141 kt (10%) organics and 15 kt (1%) tyres.
- Two thirds of all metal waste, 547 kt, was exported to be processed outside of New Zealand. This is something that would likely change when NZ Steel's planned new infrastructure is commissioned. 256 kt of metals were reported as entering landfill, mostly Landfill 1.
- 697 kt (4%) of all waste was recycled in New Zealand. This comprised 124 kt (18%) construction and demolition waste, 273 kt (39%) cardboard and paper, 102 kt (15%) glass, 13 kt (2%) metal, 28 kt (4%) plastics, 141 kt (20%) organics and 15 kt (2%) tyres.
- Composition data for landfills indicate the overall makeup of waste in New Zealand. This is dominated by 5,833 kt of rubble mostly in Landfill 5 but with contributions from Landfills 1 and 2. Rubble represented 34% of all landfill waste in this analysis.
- Organics, was the next largest category of waste identified at 1,824 kt, representing over 10% of all waste assessed. Organic waste was primarily indicated in Landfill 1 with minor contributions from Landfills 2 and 5.
- Plastics were identified primarily in Landfills 1 and 2 with a total of 1,315 kt or just under 8% of all waste analysed.
- Timber amounted to 1,380 kt of waste, or roughly 8% of all waste assessed, mostly in Landfill 2 but with additions in Landfill 1.
- Smaller quantities of paper (695 kt, 4%), textiles (395 kt, 2.3%), nappies and sanitary products (304 kt, 1.8%), metals (256 kt, 1.5%), and glass (207 kt, 1.2%) were also identified.
- Tyres in landfill were a very minor fraction at 17 kt or 0.1% of the total waste assessed. This small figure may indicate alternative handling systems or exports that do not feature in this waste flow diagram.
- A total of 807 kt of potentially hazardous waste was identified in Landfill 1, comprising 4.7% of the total waste assessed.

We understand facility-level waste information may be collected on a regular basis by individual parties as part of waste services but is commercially sensitive. Further discussion with advanced manufacturing and waste industry stakeholders about how best to request, collate and aggregate this information is recommended.

We are aware that some industries use monofills which are associated with specific businesses and do not feature in our analysis. This is recognised as a data gap and increasing the visibility of these monofills recommended.

We have been unable to specifically link these aggregated waste flows to specific activities within advanced manufacturing due to a general lack of waste data at a business or industry level. In some regions, specifically the UK and EU, reporting of business-specific waste is becoming more commonplace as part of public-facing sustainability reporting, often included alongside annual reports. Measures to encourage a similar standard of transparency and accountability in New Zealand should be considered as this would enable more detailed assessments of waste flows and more targeted interventions and investments aimed at reducing waste at the source.

Although it is difficult to confirm manufacturing as a waste source due to identified data gaps, through qualitative resource flow scan at the product level we were able to develop key waste stream characteristics associated with each sub-sector (Table 2). This demonstrated notable differences. For example organic waste is associated with only a few sub-sectors, and trends with tertiary packaging, personal protective equipment (PPE) and potentially hazadous related waste generation is identified as a common manufacturing streams that can be expected in all sub-sectors. This can be considered indicative to help inform future validation of waste associated with manufacturing to support circular interventions.

We note there are opportunities for some waste streams to be recycled or repurposed, e.g. soft plastics recycling at recycling centres (Soft Plastic Recycling New Zealand, 2024) or through commercial recycling markets for low density polyethylene (LDPE); extruded polystyrene through retailers or private transfer stations (Airpop, n.d.), or processed into SL grade (Koolfoam, 2023); wood pallets can be reused or recycled into landscaping and animal bedding (Green Gorilla, 2024; Goodwood Waste Solutions, 2024); Cargill Enterprises trialled recycling used PPE (Kennedy, 2021). However, waste diversion in practice is highly dependent on the manufacturing facility and resource recovery location, on-site sorting quality and storage capacity, and contracted waste and recycling service arrangements.

Table 2 Sub-sectors waste characterisation by waste material composition, SWAP categories

	Food and beverage	**Machinery and equipment**	**Wood and paper**	**Metals and metals products**	**Chemicals and refining**	**Plastics and rubber**	**Other manufacturing**	***Commentary***
Organics	✓		✓		✓		✓	
Cardboard and paper	✓	✓	✓	✓	✓	✓	✓	*Packaging*
Timber	✓	✓	✓	✓	✓	✓	✓	*Packaging*
Rubble/concrete (incl cleanfill)							✓	
Potentially hazardous	✓	✓	✓	✓	✓	✓	✓	*Varied*
Plastic	✓	✓	✓	✓	✓	✓	✓	*Packaging*
Metals	✓			✓			✓	
Textiles	✓	✓	✓	✓	✓	✓	✓	*Personal Protective Equipment*
Nappies and sanitary	✓	✓	✓	✓	✓	✓	✓	*Personal Protective Equipment*
Glass	✓						✓	
Rubber (incl tyres)		✓					✓	

This qualitative approach was also useful by highlighting the re-use or repurposing of waste products, as co-products, by-products or the application of circular solutions internally such as for energy or inputs for further manufacturing processes. It was observed that by-products could either be on-sold or given away to benefit other sectors. Examples include blood and bone from meat manufacturing into fertiliser (Moodie, 2021) or slag from steelmaking into cement and pavement additives (New Zealand Steel, 2023). Food and beverage had frequent occurrences of circularity demonstrated through co-product and by-product use (See section 5.7.3, food and beverage).

Advanced manufacturing was also found to be a waste solution through re-manufacturing, with close links to the waste and resource recovery sector when relying on raw material inputs. For example, plastic waste can be manufactured into building materials and panels (SaveBoard, 2023), cabinetry (Critical, 2023) or packaging (PACT Packaging, 2023).

4.3. Activity location

Our approach to advanced manufacturing geospatial mapping aims to highlight sub-sector profile location trends and regional differences and the potential for these to inform decarbonisation and circular opportunities. Manufacturing activity base on 2019 business and employee count information is shown in Figure 11 and Figure 12.

Figure 11 Manufacturing activity location heatmap – businesses ANZSIC L1 by territory, Stats NZ 2019

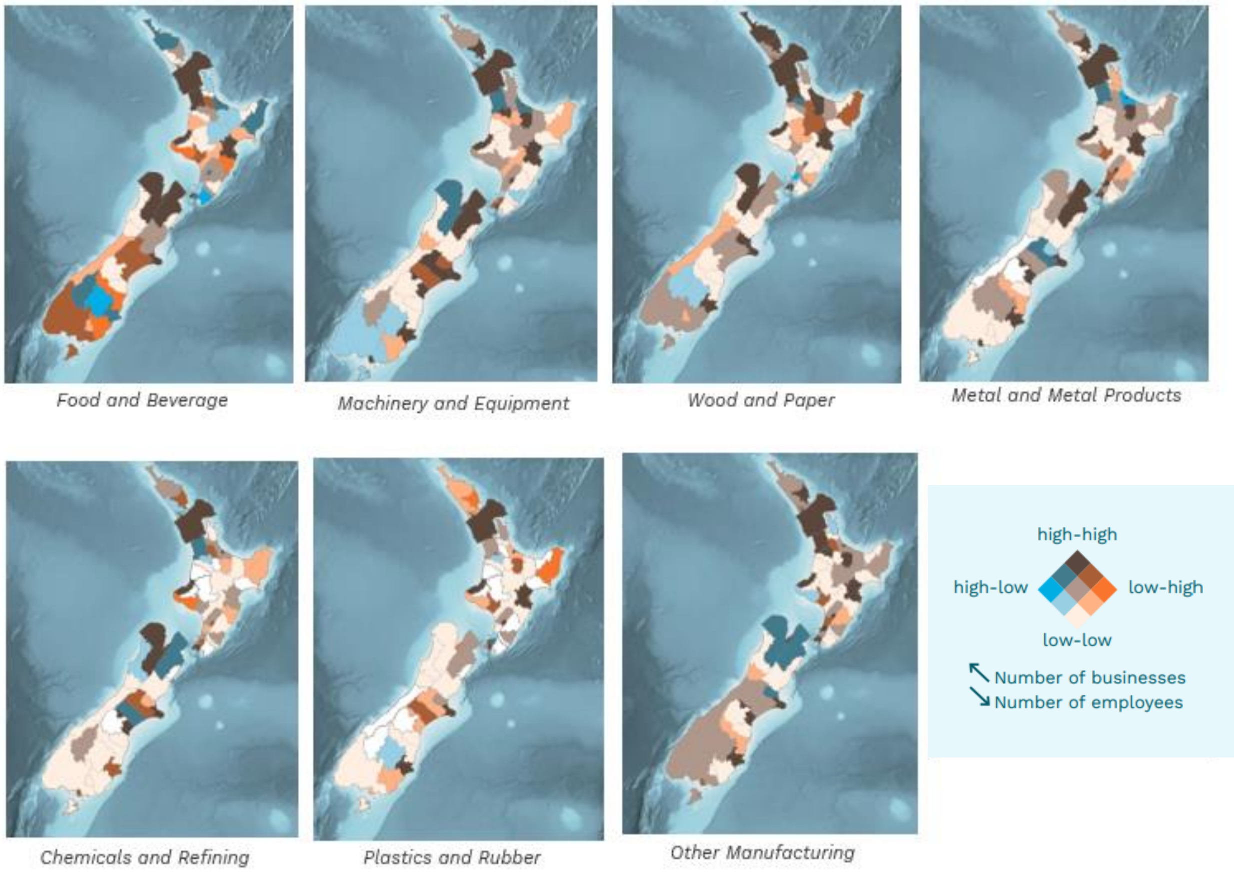

Figure 12 Manufacturing activity location - business and employee count ANZSIC L2 by territory, Stats NZ 2019

It is important to effectively overlay different data points to capture manufacturing activity by location, including consideration of:

- Region, district, and territory
- Advanced manufacturing sub-sector activity to ANZSIC06 level 3
- Company size by employee count
- Emission intensity from top-down data set
- 2019 alignment.

Although revenue data was accessible for sub-sectors, due to aggregation challenges and commercial confidentiality we were unable to link these to location. However, we were able to use the number of employees and district and number of businesses as a proxy for sub-sector activity in an area.

We also note limitations with head offices included within Stats NZ figures, which may not be associated with manufacturing facilities at that site.

Collating sub-sector activity by location aimed to enable investigations into:

- Putting a regional lens on advanced manufacturing considering revenue and business size.
- Understanding clusters of activity and related circular and decarbonisation opportunities.

- Identifying region-specific considerations to support circular advanced manufacturing.

These are included within sub-sector sections at ANZSIC L2 and L3, highlighting key areas within NZ related to that sub-sector. GIS visualisations have been compiled in a geoportal allowing for filtering at a granular level, with potential for other data such as revenue to be added at a future date.

4.4. Stakeholder perspectives

In this project we engaged with more than 250 different stakeholders through workshops and interview activities. This highlighted the difficulty in gathering detailed data on various advanced manufacturing areas. Stakeholders stressed the importance of improving data collection for deeper insights. A key issue was the need for clearer definitions, especially for emissions from production versus consumption. Major gaps include a limited understanding of material longevity, the state of assets in New Zealand (like buildings and machinery), product lifecycles, and the trade and emissions of used products. Enhancing knowledge in these areas is crucial for future sustainability efforts. This could involve obtaining data from businesses, finding new data sources, and improving industry-government collaboration.

Circular economy practices such as product-as-a-service, repair, remanufacturing, and turning by-products into raw materials (industrial symbiosis) were identified as ways to advance sustainability. These strategies need to be evaluated for their practicality and impact in New Zealand. The value of spatial and regional data was also noted for customising material management and lowering emissions. This is particularly relevant for certain industries, like dairy in the food and beverage sector. The discussions also highlighted the benefits of designing reusable products and cross-sector collaboration.

The need for industry-led innovation and supportive policies was identified. This included having sustainability leaders within companies and understanding circular business models to guide decision-making and investment. It also covered the necessity for regulations and incentives to adopt circular economy principles and to address the challenge of monitoring emissions and waste.

A systemic approach to sustainability was seen as essential, along with clear reporting on waste and emissions. This transparency is key to encouraging the use of innovative materials and processes and promoting collaboration across sectors. The discussions emphasised that converting complex data into actionable insights is vital for moving towards a net-zero circular economy.

The stakeholder engagement revealed both challenges and opportunities in enhancing sustainability and circular economy practices in manufacturing. It showed a strong commitment to these principles, underlining the importance of accurate data, cooperation, and technology in tackling environmental issues and highlighting the continuous effort needed to achieve sustainable practices.

5. Food and beverage sector

5.1. Sub-sector overview

The food and beverage sub-sector makes up a significant part of New Zealand's advanced manufacturing sector. It is the country's largest advanced manufacturing sub-sector and a major export industry, accounting for almost half of the total goods and services exports. Food and beverage contributes the largest sub-sector percentage of GDP (32%), is the largest employer and captures the largest percentage of manufacturing foreign direct investment (FDI) of the sub-sectors (53% from the $18.88 billion of total FDI).

Major players include Fonterra, Silver Fern Farms, ANZCO, Sanford, Sealord, Talleys Group, Heinz-Watties and Griffins. Of note, these have varying types of business structures including co-operatives, corporates, multi-nationals, SMEs. In many instances these are vertically integrated or have strong links to primary sector inputs and logistics.

In the last ten years, this sector has seen a surge in international interest, with many international companies such as Yili, Yashili, Danone, Olam, and a2 Milk building or acquiring dairy assets in New Zealand. This has further bolstered the food and beverage sector, reinforcing its position as a key player in New Zealand's advanced manufacturing sector.

Further work includes consideration of the food and beverage sub-sector in relation to the wider food system in New Zealand, including food security and retailing, food loss and waste, packaging, and manufacturing as an enabler for upcycled food.

The food and beverage sector can be categorised into various segments, with data from different sources aggregating to different levels. Achieving concordance between these levels was a key part of the top-down analysis. Top-down emissions data for the food and beverage sector in New Zealand is published by Stats NZ under five categories. This contrasts with the ANZSIC Level 3 categorisation which expands this to 11 categories, shown in Table 3. Because the Stats NZ emissions data is consolidated to a higher level than the economic data, there are more assumptions required, and more uncertainties for categories such as fruits and vegetables, bakery products, or oils and fats.

Table 3 Correlation of NZSIOC and ANZSIC Level 3 data formats

NZSIOC (Stats NZ Emissions Data)	ANZSIC Level 3 (Stats NZ Economic Data)
Meat & Meat Products	Meat & Meat Products
Seafood	Seafood
Dairy Products	Dairy Products
Fruit, Oil, Cereal, and Other Food Products	Fruit and Vegetables
	Oil and Fat
	Grain Mill and Cereal Products
	Bakery Products
	Sugar and Confectionary
	Other Food Products
Beverage & Tobacco	Beverages
	Cigarettes and Tobacco

New Zealand's food and beverage manufacturing is predominantly seasonal. However, many food and beverage markets have inherent seasonality have set up global supply chains to offset this. With food affordability and availability identified as future issues, the New Zealand food and beverage market will need to adapt to meet consumers' sustainability expectations and maintain its reputation. For export-driven markets, local pricing is strongly connected to international value and price, particularly for high-quality export products.

5.2. Top-down assessment

5.2.1. Greenhouse gas emissions

The EIO-LCA methodology calculates the marginal carbon impact of an extra dollar spent in a given sector. This is a form of a *consequential LCA* and is notably different to an *attributional LCA*, which is generally used for static benchmarking. This consequential model better accounts for changes in spend, revenue and emissions but can be challenging to compare directly with a standard attributional LCA.

In this way, it differs from a product-driven methodology, and allocates emissions across the economy more broadly. An example of this is the dairy processing sub-sector. The economic input-output data from Stats NZ shows that, for an additional $1 spent in this sector, $0.58 is spent within the dairy farming sector, and $2.46 across the entire economy (Stats NZ, 2021). Using a flat financial allocation approach, this means that only 23% of the emissions from the dairy sector are attributed to the dairy processing sector.

In an attributional LCA, the emissions from the dairy farming sector would be substantially allocated to the dairy products themselves (albeit shared with co-products from the dairy industry such as leather) and would likely be higher than a 23% share as a result.

Similarly, emissions from additional sectors within the dairy processing supply chain are allocated to the manufacturing industry, such as road transport and banking and finance (2% and 1% of marginal dairy processing emissions, respectively.)

The differences between attributional and consequential methodologies were intended to be explored in early 2024 through the development of both top-down and bottom-up modelling approaches, as more detailed data became available. While this environmental-economic accounting approach is difficult to compare directly with a typical LCA, it is aligned with the methods used by Stats NZ and similar international governmental agencies for country-wide emissions accounting – based off the System of Environmental-Economic Accounting 2012 (United Nations, 2014) and the System of National Accounts (United Nations, 2009).

Data is presented as being from direct production (excluding supply chain impacts) and from an industry consumption perspective (including supply chain impacts). Both accounting for total production, and local consumption (excluding exported products).

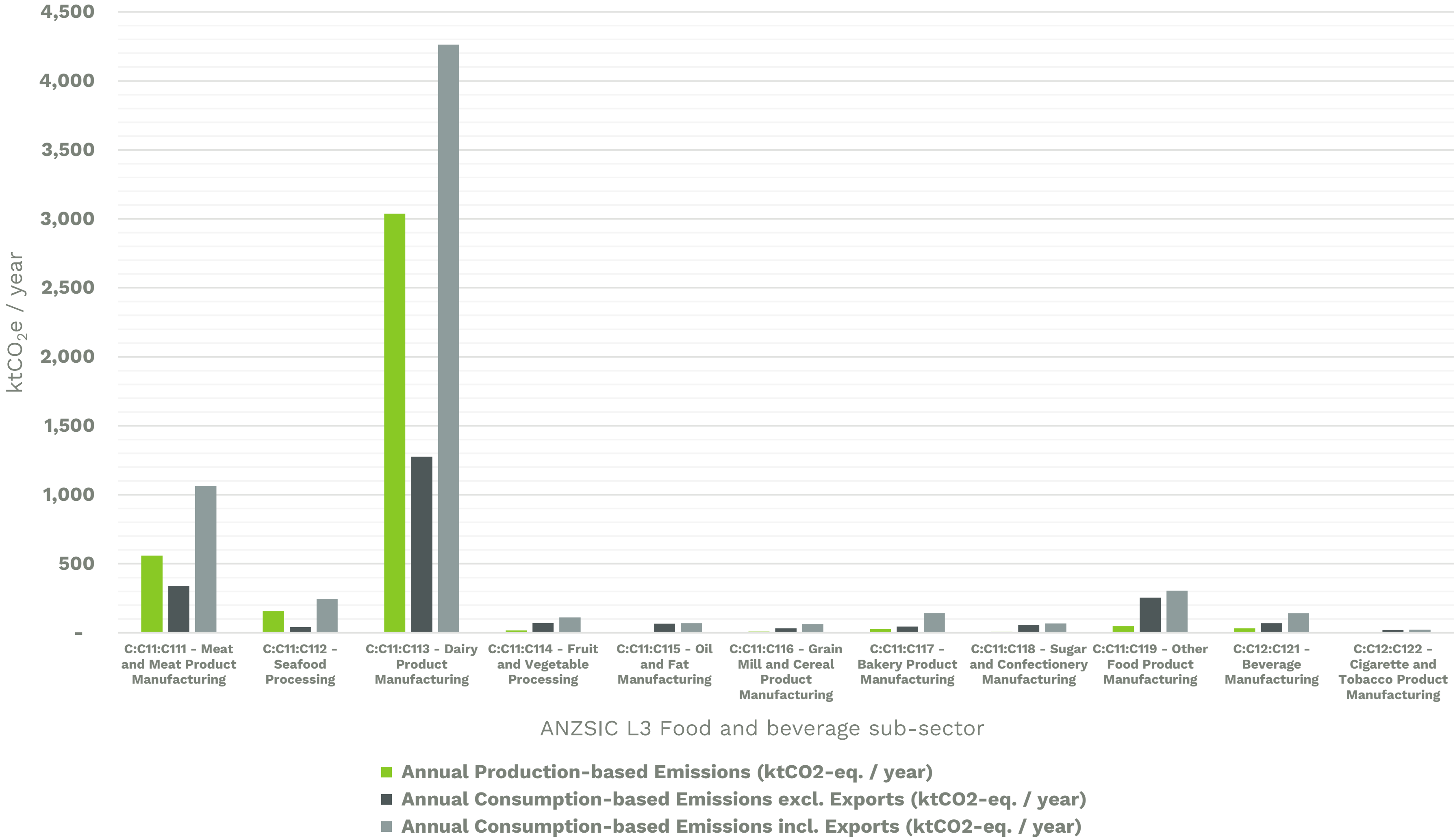

Figure 13 Annual production- and consumption-based emissions from the food and beverage manufacturing sector (ktCO₂e / year), 2019 baseline

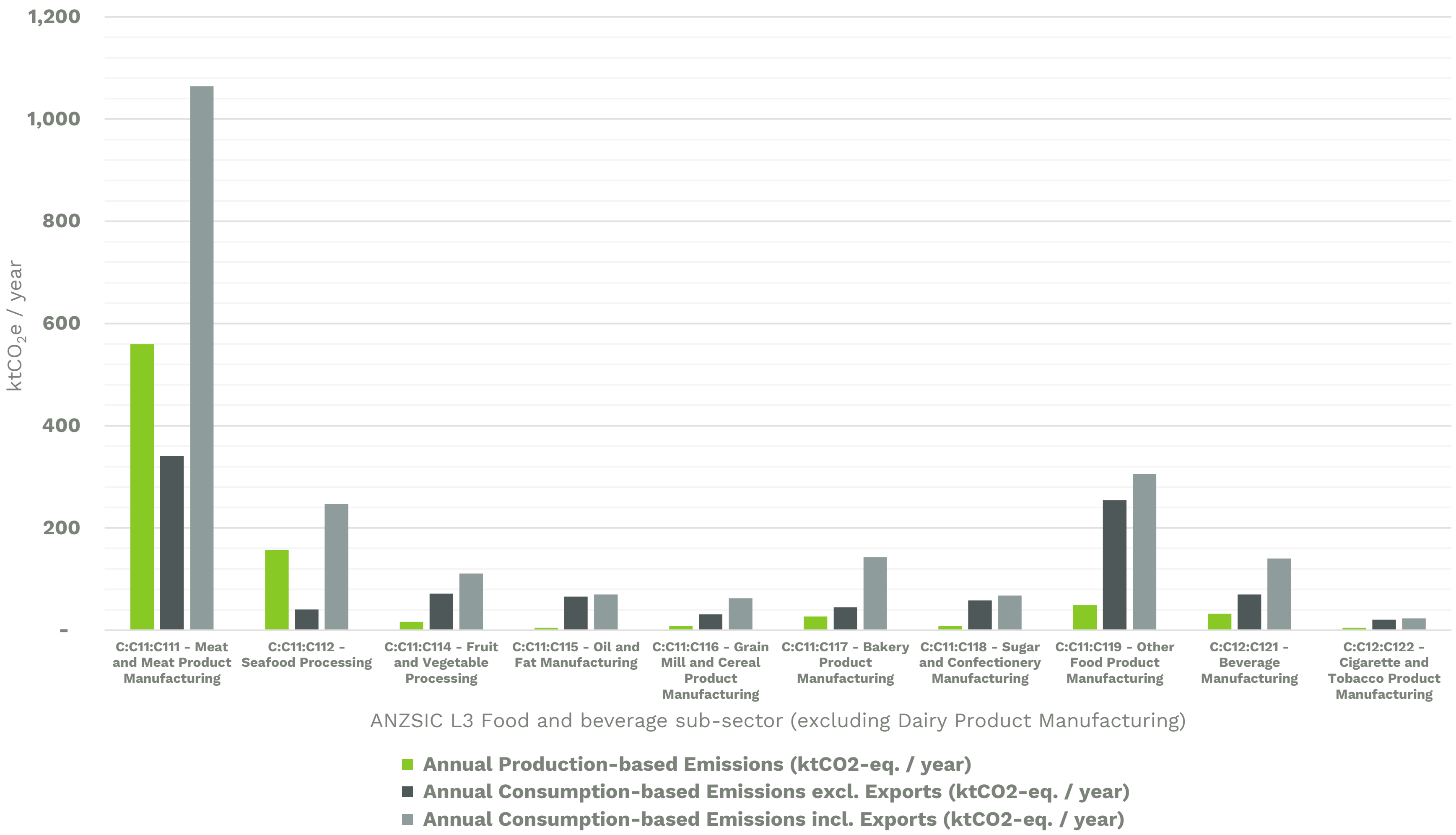

Figure 14 Annual production and consumption-based emissions from the food and beverage manufacturing sector, excluding Dairy product manufacturing ($ktCO_2e$ / year), 2019 baseline

Through top-down analysis, it is shown that emissions from the food and beverage manufacturing sector are dominated by the dairy product manufacturing sub-sector (Figure 13). Considering dairy accounts for most of this industry's emissions (82% on a production basis), this could be an area where considerable emissions reductions could be made to the overall food and beverage sector, and we note that progress has occurred in this industry since the 2019 base year.

It is also apparent that the production-based emissions are much larger for both meat and dairy products than their consumption-based emissions (1.6x for meat, 2.4x for dairy), indicating that most of the manufactured goods are not consumed by domestic residents – indicating this is primarily an exporting sub-sector. This is confirmed when looking at the domestic production and export numbers (Figure 13). This puts into perspective the impact that exports have on emissions accounted for using the consumption approach. When accounting for supply-chain emissions, we see that domestic consumption for the dairy and meat sectors is lower than production-only. Including goods manufactured for export increases these emissions significantly and may provide a fairer comparison to production-based figures.

Across the food and beverage sector, there are two sub-sectors dominated by exports which are much larger than the others, with the remaining sub-sectors smaller and import-dominated. Considering that many of the products from these sub-sectors are related, there may be an opportunity to reduce import-dependence in these smaller sub-sectors through implementing circular economies. An example may include fats being a by-product of the meat and meat product sub-sector.

Seafood manufacturing is somewhere between meat and dairy, and the smaller import-driven sub-sectors. Seafood is a net exporter but is a much smaller industry than meat for example (157 versus 560 ktCO_2e in 2019).

Removing dairy from analysis shows that the smaller sub-sectors contribute similar amounts to the total emissions for the food and beverage sector, both from a production and consumption-based approach. Within these smaller sub-sectors there is a common theme of a negligible production emissions footprint, and much larger consumption-based figure. This may indicate that we primarily import these goods but is also indicative of the lower emissions intensity of these sub-sectors as shown in Figure 14.

In the development of emissions intensities for these sub-sectors, this is the first instance of data gaps and a lack of granularity. Production-based emissions data used as a reference for this analysis is provided in a format less granular than the required breakdown to ANZSIC level 3. The result of this is a 'one-to-many' mapping between these emissions intensities and their resulting sub-sector. Fortunately for the food and beverage sector, the main contributors, meat and meat products and dairy product manufacturing, have consistent categories in all the relevant classification systems so no estimation is required.

As total emissions are a function of not only the amount of production and consumption, but the intensity of production itself, it is important to assess where sub-sectors are simply less carbon efficient than others through their emissions intensity, as shown in Figure 15.

Emissions intensities show how much carbon is emitted as a function of the industry's revenue. It suggests that some sub-sectors are less carbon-efficient and require more energy use or have a larger supply chain burden than others to produce the same amount of economic benefit. Intensities for the food and beverage sector follow a similar trend to the emissions totals themselves, except for seafood processing which is more carbon-intensive than meat and meat products from both a production and consumption-based approach. This is surprising as, considering the agricultural and fertiliser requirements for meat manufacturing, one may expect this to be larger. Given research into this sector suggests that NZ shellfish and salmon processing is generally low-emissions, this may be an artefact of the modelling methodology, or related to lower revenues in the seafood processing sector compared to other sub-sectors (Warmerdam & Vickers, 2021; thinkstep-anz, 2023) .

The large production intensity for dairy, and relatively small gap between production and consumption values, indicate there is a large component of emissions from the actual manufacturing processes here. These are described in more detail in the food and beverage deep dive and show the large energy requirements for processes such as milk powder drying, and the reliance on fossil-fuels as energy sources for much of this plant.

In the intensities of emissions, we first see issues with a lack of granularity in the data – one-to-many mappings. To observe the effect of this lack of granularity due to mapping discrepancies, a sensitivity analysis was completed for a select group of manufacturing sub-sectors. This analysis looked to develop separate emissions intensities for each sub-sector at ANZSIC level 3 using external resources to see how large an effect the one-to-many mapping was having on the data. The results of this analysis are included in Sensitivity analysis, Section 13.

There are other limitations in the development of this top-down data set that permeate all sections of the account, namely the use of NZ emissions intensities as proxies for internationally manufactured commodities and products. Consumption-based emissions accounting looks to include the effects not only of domestic production, but of those goods and services imported from overseas. These goods and services will have different emissions intensities from NZ based on a range of factors including their energy makeup, transport types and distances and supply chains, etc. As with the one-to-many mappings, a sensitivity analysis around this issue was completed to observe the effect it was having on the data output. The results of this analysis are also included in Sensitivity analysis, Section 13.

In the implementation of circular economy initiatives, it is important to note the regional nature of these opportunities. The ability to use different co-products and by-products within sectors depends on the proximity of these sub-sectors, and the availability of infrastructure in these regions to support implementing circular strategies. Activity location, Section 4 shows the methodology behind understanding how these advanced manufacturing sub-sectors are spread across NZ, through the lens of business and employee numbers and business sizes. This data was used as a proxy for manufacturing sub-sector activity and in lieu of regionalised emissions data to allocate sub-sector emissions across New Zealand's territorial authorities.

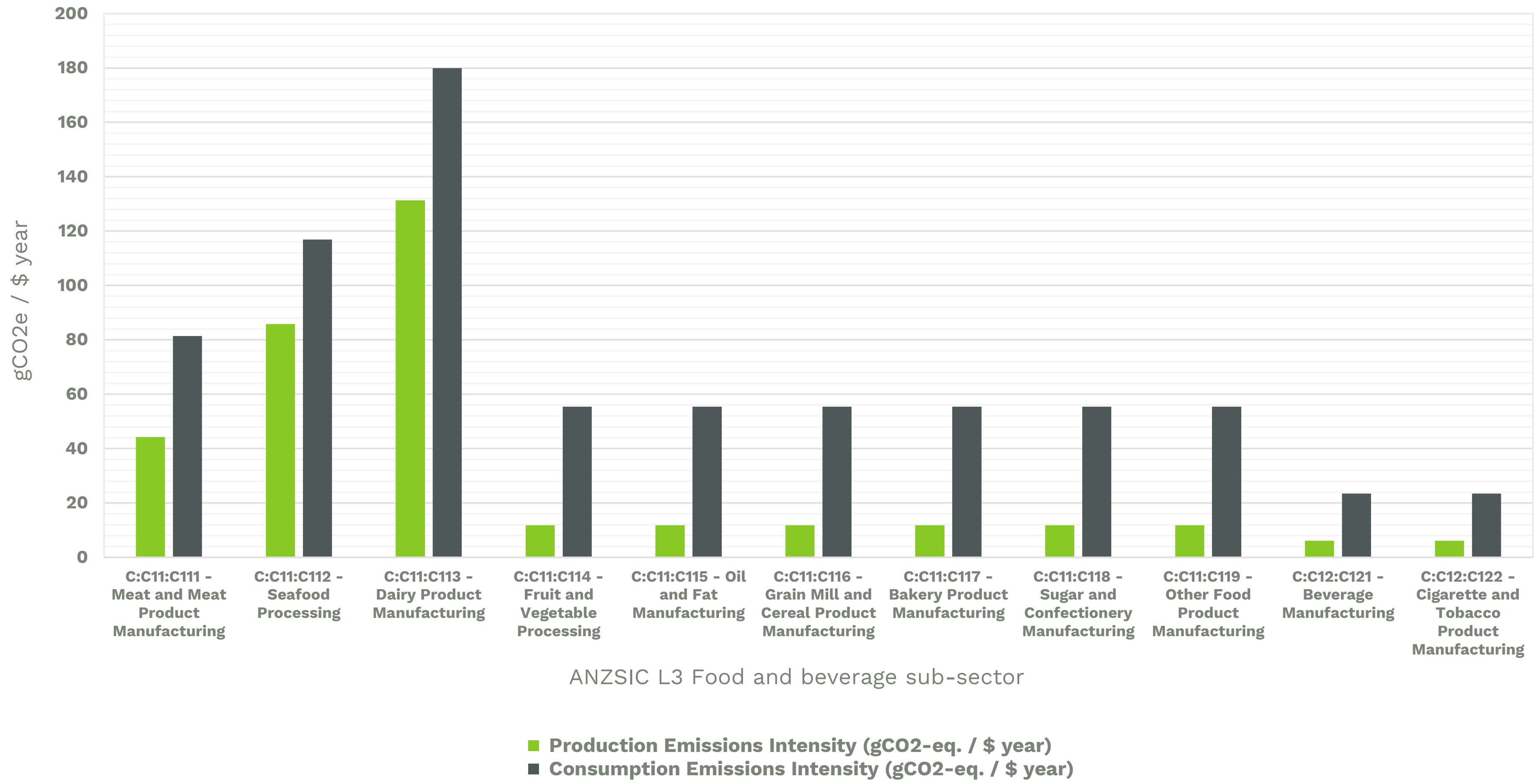

Figure 15 Annual production- and consumption-based emissions intensity of the food and beverage manufacturing sector (gCO$_2$e / dollar – year), 2019 baseline

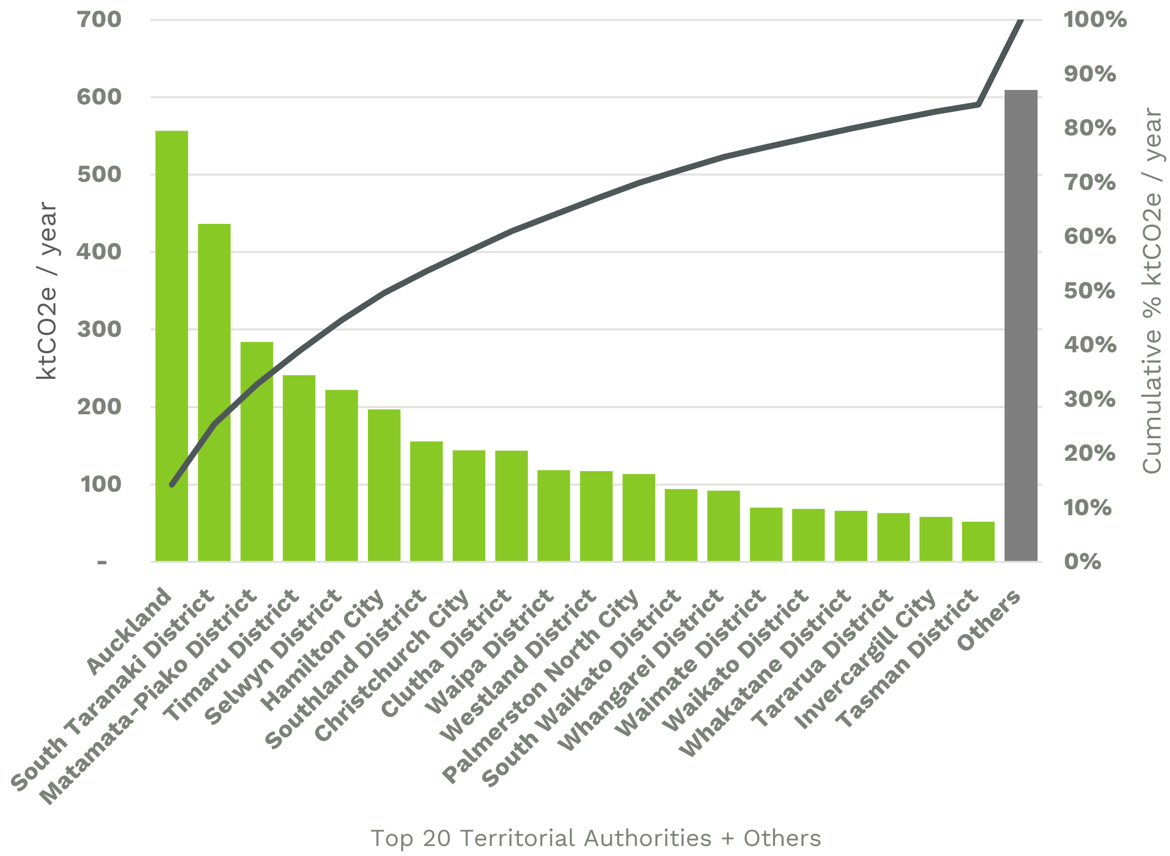

Figure 16 Annual production-based emissions from the food and beverage manufacturing sector across NZ territorial authorities (ktCO2e / year), 2019 baseline

When looking at the regional breakdown of emissions across the food and beverage sector we see Auckland alone accounts for approximately 14% of the total. As the largest territory in New Zealand this makes sense, but this may also be a result of the location of head offices of food and beverage companies – due to the nature of the data used for regionalising the emissions data. Regions in the Waikato and southern districts follow, which is aligned with where much of New Zealand's farm and agricultural land is located. Territorial Authorities outside the top-twenty make up around 16% of the total, which is more significant than Auckland alone, showing this sector is relatively well distributed around the country.

Overall, food and beverage, from a top-down emissions account standpoint, is a large emitting sub-sector that is export-driven and very diverse. With many small sub-sectors still import-driven there may be opportunities to bring production into New Zealand and reduce import reliance, potentially through implementation of circular practices.

5.2.2. Waste

Focusing on potential food and beverage manufacturing waste generation, the following associated streams are outlined in Table 4.

Through qualitative resource flow scan activities, we identified potential waste outputs associated with production. It was found organic-related resource flows dominate food and beverage manufacturing, with potential food loss through logistics and processing stages. We note co-product and by-product resource streams are well established. Pet food is an example within the sub-sector and blood and bone fertiliser inputs into chemical and refining is another. Personal protective equipment (PPE), packaging and contaminated waste outputs related to washing systems were prevalent waste streams across sub-sectors. We note by sub-sector that supply chain inputs and processing vary significantly depending on product and directly relate to waste generated and opportunities to close the loop through diversion activities. Further investigation is needed on waste streams and diversion associated directly with food and beverage primary packaging lines, for example plastics, cardboard and paper, glass and metals waste (versus secondary or tertiary packaging sources) and is expected to be closely related to end-product format.

Table 4 Food and beverage waste characterisation by waste material composition, SWAP categories

	Food and beverage	Identified source examples
Organics	✓	Food loss, fibrous biomass, defective product, spent grain, shells
Cardboard and paper	✓	Packaging
Timber	✓	Packaging
Rubble/Concrete incl. cleanfill	-	-
Potentially hazardous	✓	Expired or excess chemical, sludge
Plastic	✓	Packaging
Metals	✓	Packaging
Textiles	✓	Personal protective equipment
Nappies and sanitary	✓	Personal protective equipment
Glass	✓	Packaging
Rubber (incl tyres)	-	-

5.3. Bottom-up assessment

5.3.1. Qualitative resource flows

Part of the resource and waste mapping for the food and beverage sub-sector included the development of material flow diagrams at ANZSIC level 4. These identify the key product, input resources, and output co-products, by-products, and waste products. They also identified opportunities for circular resource flows across ANZSIC levels 3 and 4. Sub-sector material flow diagrams completed to date include:

- C1214 Wine (Figure 17)
- C1212 Beer (Figure 18)
- C1120 Seafood (Figure 19)
- A combination of C1230 Leather; C1111 Meat; and C1311 Wool Scouring (Figure 20)

These flow diagrams are shown on the following pages. Overall, this exercise identified some key findings and opportunities:

- Agriculture and farms are a common end user of by-products or waste resources from advanced manufacturing. Fertilisers for farms can be derived from meat processing (Moodie, 2021) (Figure 20), seafood processing (Figure 19), milk and cream processing (Piddock, 2017).
- Non-human consumables are also common from food and beverage by-products such as grape marc (Roodposhti, 2022) and pet food ingredients from meat processing, poultry processing, and fruit and vegetable processing (Royal Canin, 2023).
- There are examples at different scales of waste products from food and beverage being repurposed as biofuel, e.g. tallow from meat processing (Moodie, 2021) or yeast slurry from beer making into industrial ethanol (NZ Herald, n.d.).
- Waste fruit, bread and by-products from milk can all be turned into alcohol (Love Food Hate Waste, 2023).
- Recycled beer grains can be turned into edible crackers (Noon, 2022).
- Pet food is also a common use of by-products and waste from food manufacturers, particularly meat (Sanford Limited, 2023), grain and cereal.
- Processing emissions can be reduced through pinch analysis and process integration methods of process heat recovery. Pinch analysis helps map and assess existing process heat hotspots, has been applied in the chemicals and refining, pulp & paper, and food & beverage sectors, but not widely (Atkins, 2019).
- Recovery of process heat is quite common in the dairy industry but could be expanded through increasing of heat exchanger surface areas (Atkins, 2019).
- The beverage industry is actively treating and reusing purified process water (Hydroflux Industrial, n.d.).

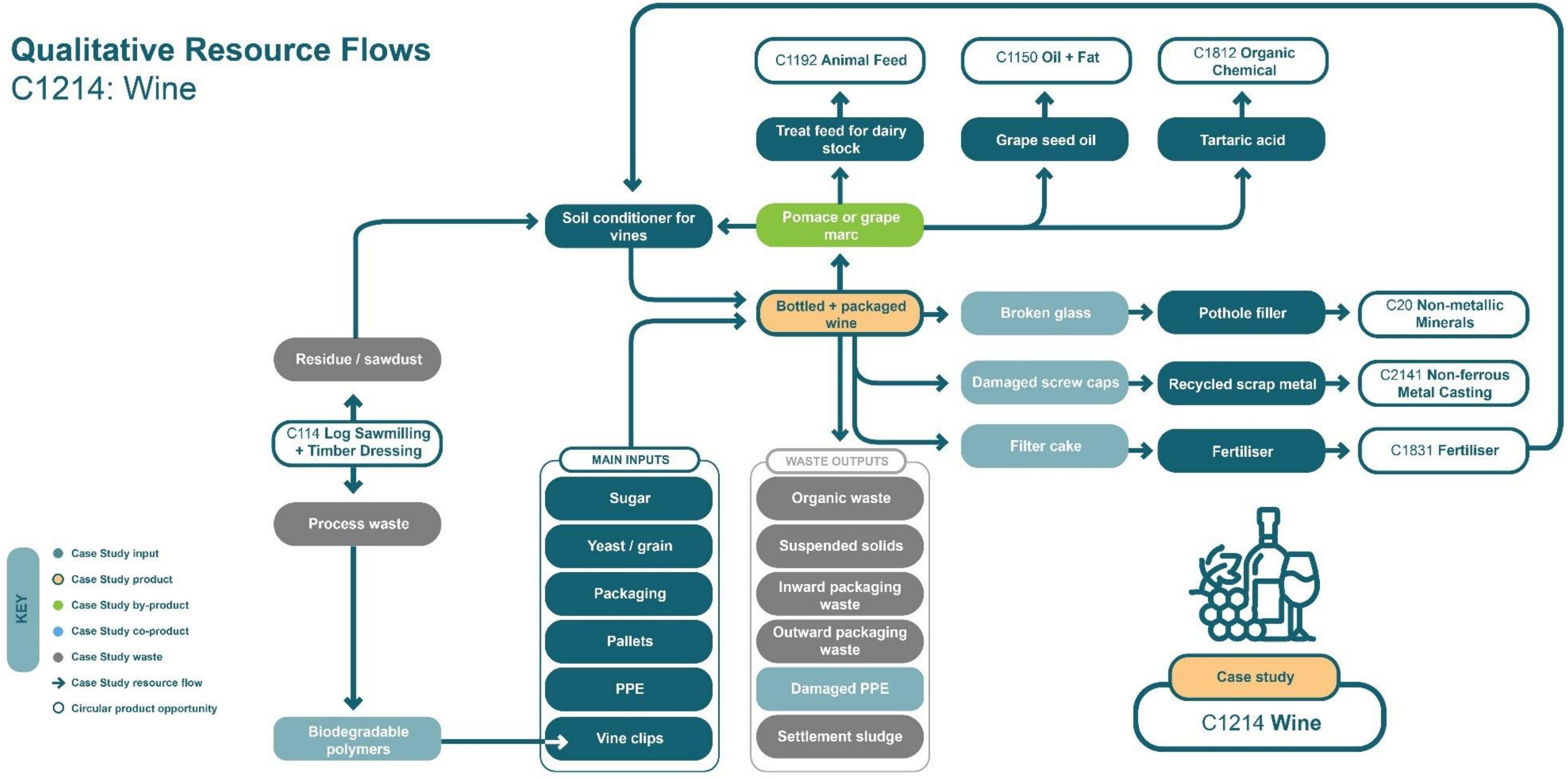

Figure 17 Resource flow map for Wine (C1214)

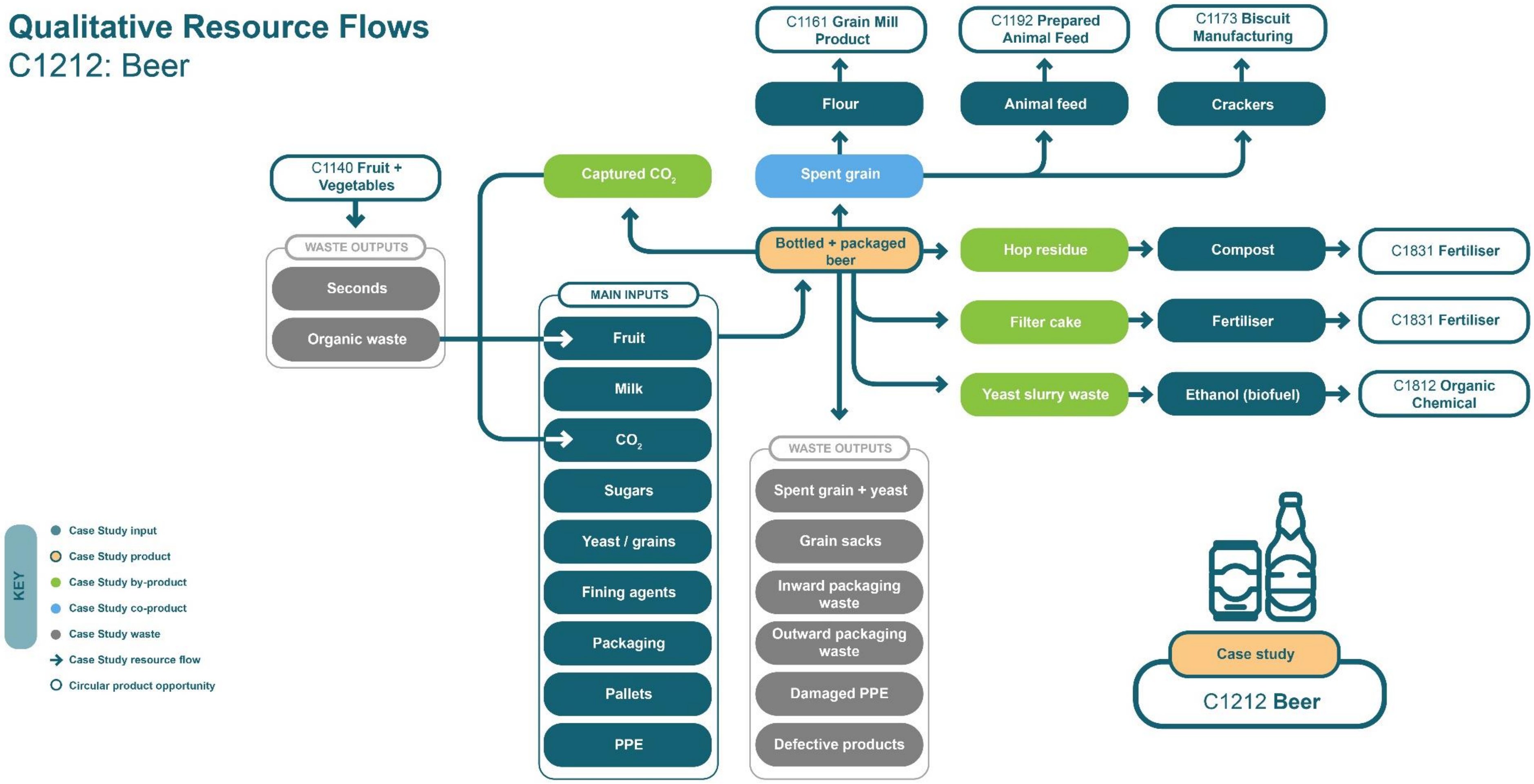

Figure 18 Resource flow map for Beer (C1212)

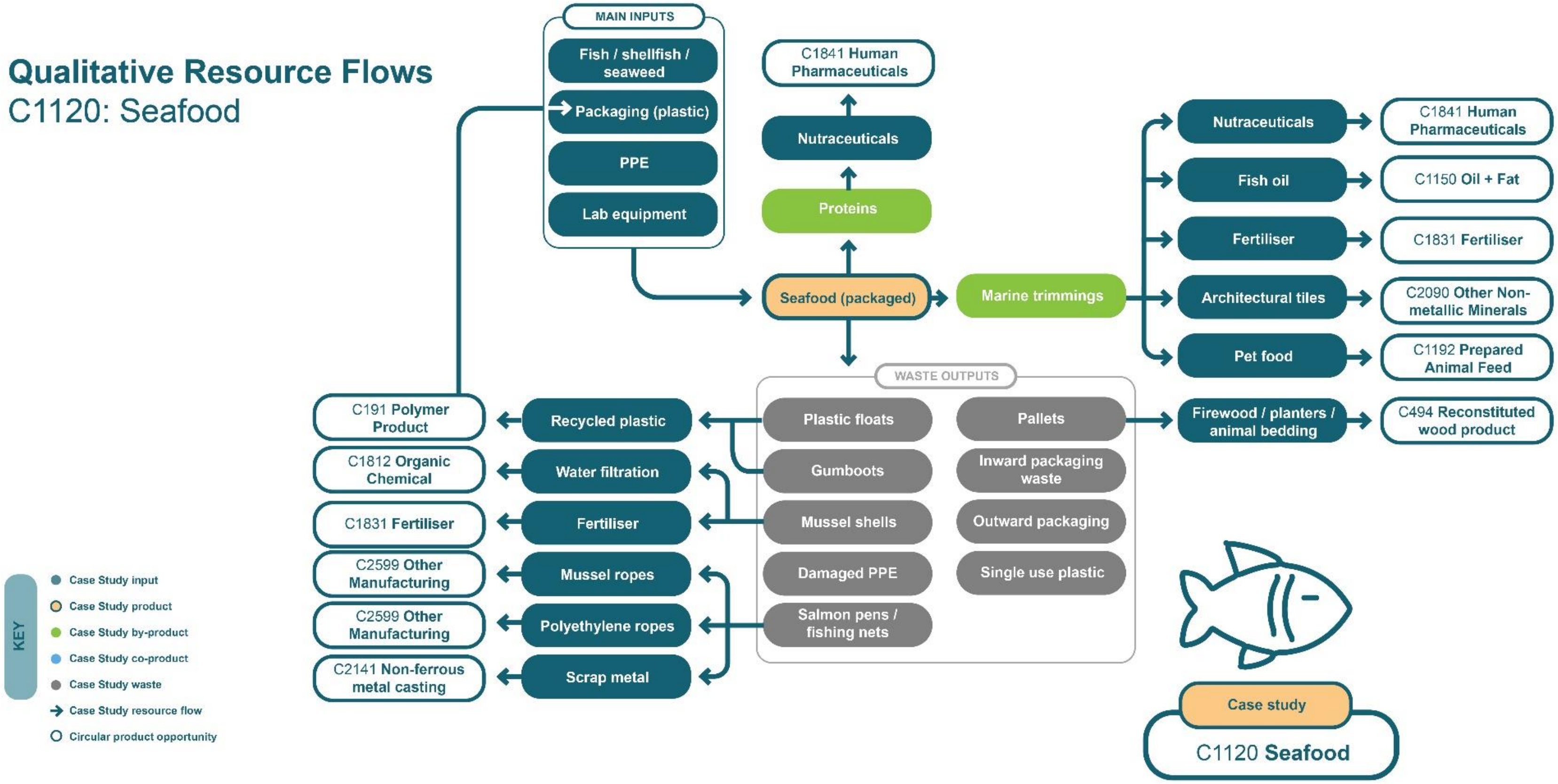

Figure 19 Resource flow map for Seafood (C1120)

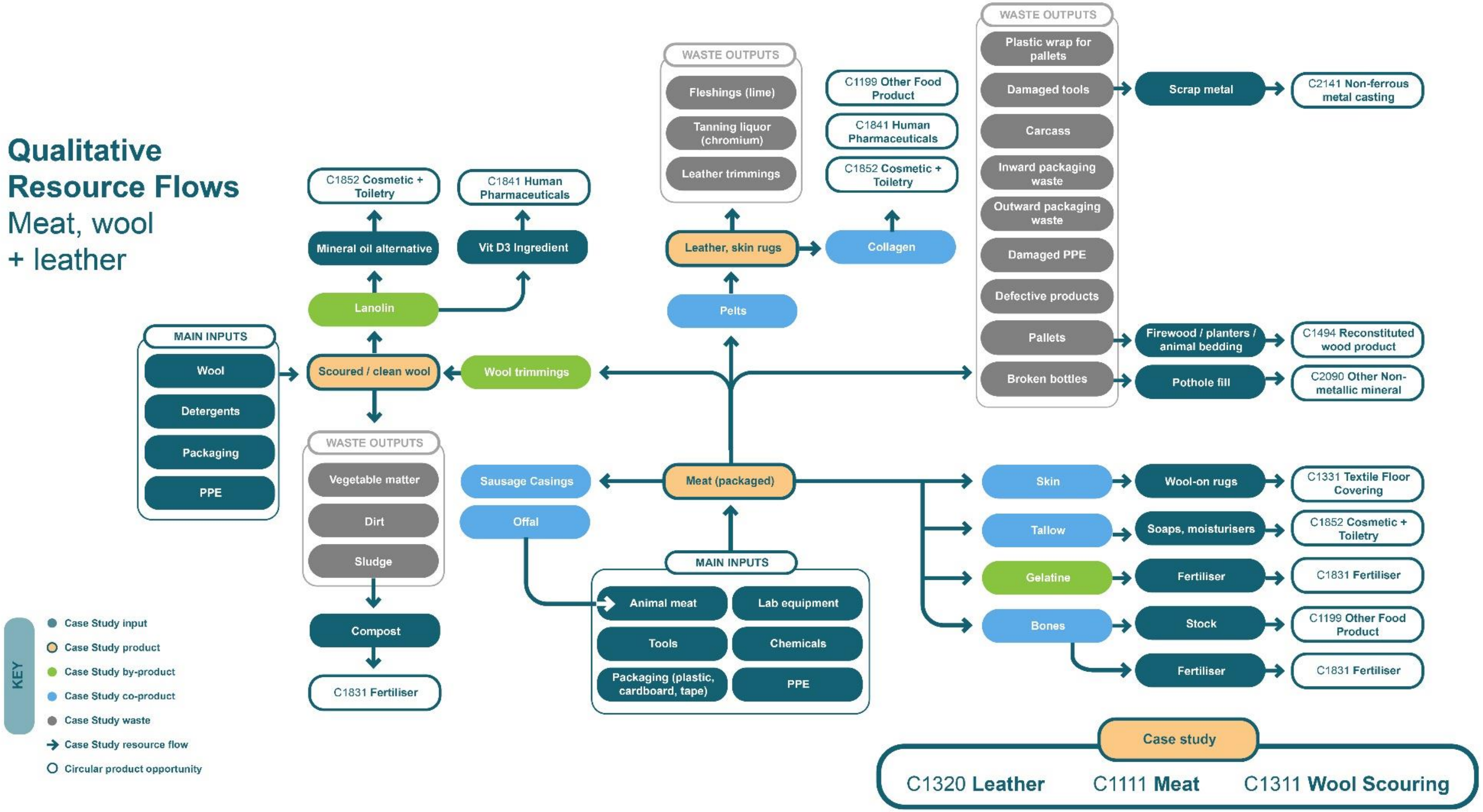

Figure 20 Resource flow map for Meat (C1111), Wool (C1311) and Leather (C1320)

5.3.2. Key material flows

Carbon emissions of the dairy industry of New Zealand, 2019

Main sources: MPI, Dairy NZ, Fonterra, FAO

(unit in kt CO2-eq)

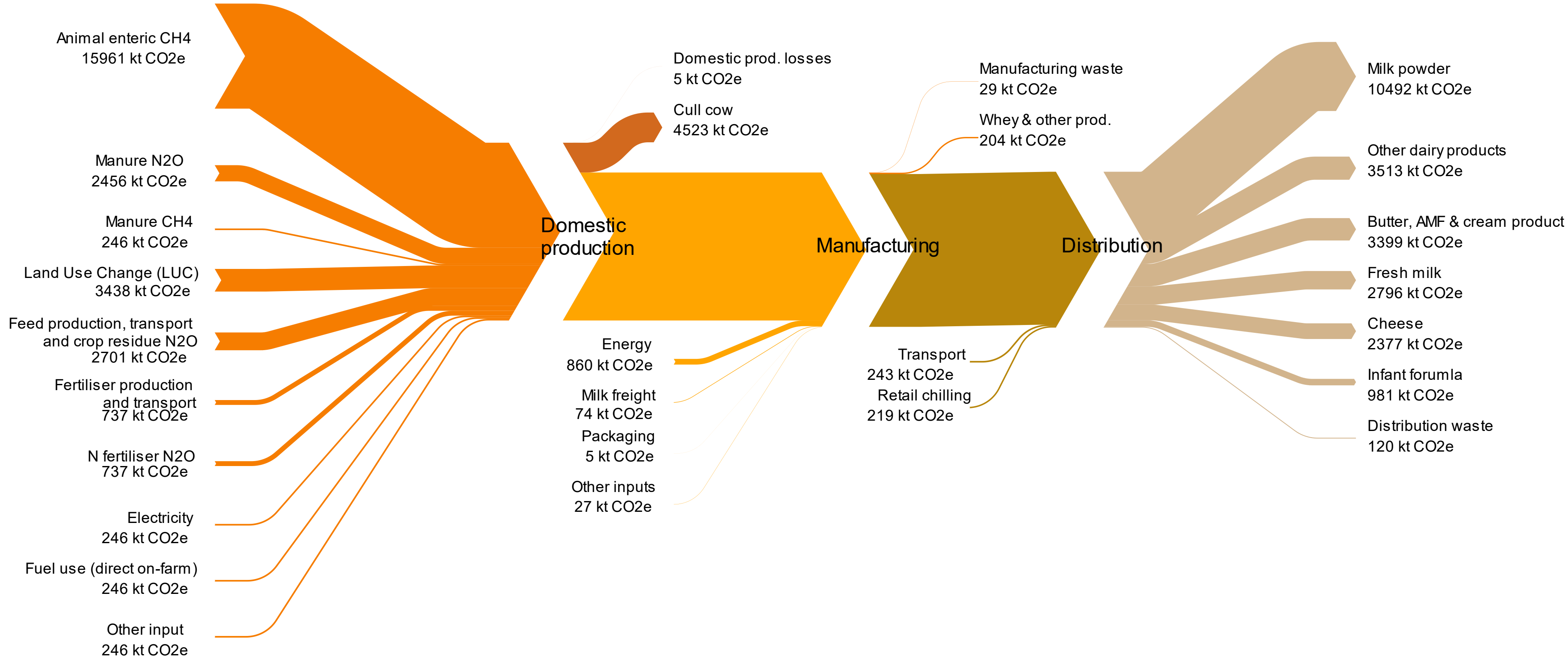

Figure 21 Carbon emissions of the New Zealand Dairy industry (2019)

5.3.3. Hotspots identified

With reference to Figure 21, the following features were noted:

1. **Animal-Related Emissions:** The largest share of emissions (15,961 kt CO_2e) originated from animal-related sources, particularly from enteric fermentation (methane, CH_4), which significantly surpassed other sources. Manure management also contributed to both methane and nitrous oxide (N_2O) emissions at 2,456 and 246 kt CO_2e respectively.
2. **Land Use Change:** Emissions from land-use change were substantial (3,438 kt CO_2e), indicating the environmental impact of altering land for dairy farming, which may include deforestation or other changes that release carbon stocks.
3. **Feed and Fertiliser:** There was a notable emission contribution from the production and transport of feed, crop residues (2,701 kt CO_2e), and the production and transport of fertilizers (737 kt CO_2e), pointing to the carbon intensity of these inputs.
4. **On-Farm Energy Use:** On-farm energy use (electricity and fuel) has a smaller but still significant impact (246 kt CO_2e), reflecting the direct energy requirements of dairy farming operations.
5. **Stock Losses:** Emissions of approximately 4,523 kt CO_2e were associated with cattle that were culled and a further 5kt CO_2e with other domestic production losses – pointing to possible improvements that might arise from enhancements in animal health and production efficiencies.
6. **Manufacturing and Distribution:** In the manufacturing stage, energy use is the largest contributor (860 kt CO_2e), followed by waste from manufacturing (29 kt CO_2e). In the distribution phase, transport and cold-chain emissions accounted for 243 kt CO_2e and 219 kt CO_2e respectively. The emissions are more diversified across different dairy products, with milk powder being the highest (10,492 kt CO_2e), followed by other dairy products (3,513 kt CO_2e), butter, AMF and cream products (3,399 kt CO_2e), fresh milk (2,796 kt CO_2e) and cheese (2,377 kt CO_2e).

The diagram visually represents where the most significant carbon emissions occur within New Zealand's dairy industry. This information is critical for policymakers, industry stakeholders, and environmental groups, as it helps identify the most carbon-intensive areas of the production process. Efforts to mitigate climate change in the sector could be effectively focused on these areas, for instance, by seeking to reduce methane emissions from livestock, improving feed efficiency, adopting more sustainable land-use practices, and optimising energy use.

5.4. Location

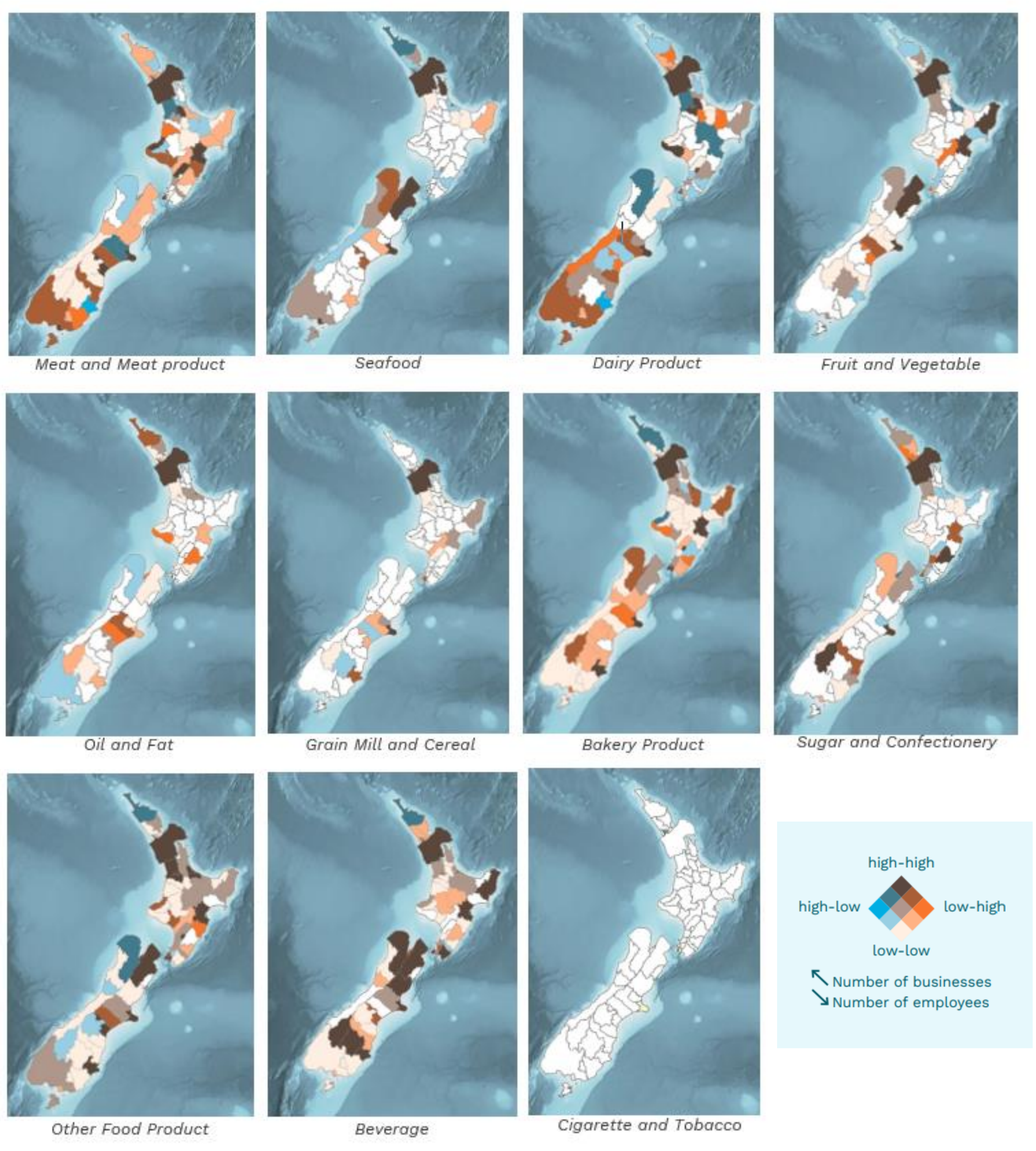

Figure 22 Manufacturing activity location – food and beverage ANZSIC Level 3 by territories, 2019

Food and beverage manufacturing in Auckland is a significant part of the NZ manufacturing sector, employing over half of NZ's work force in food and beverage manufacturing and wholesaling (Infometrics, 2016). With 18% of manufacturing businesses in Auckland in the food and beverage sector, it is home to the largest manufacturing cluster in the country and provides a well-developed ecosystem for multinationals, as well as large and small firms (Stats NZ, 2021).

However, it is important to note that while many companies may have their head offices in Auckland, the food and beverage sector has a strong regional focus. For instance, the Gisborne area had the largest concentration of fruit and vegetable processing (Tipu, 2023), and Canterbury has a large concentration of bakery products; other food manufacturing; and meat and meat product businesses (Saunders, Guenther, Driver, & Dalziel, 2020). This regional focus is a key characteristic of the sector and contributes to its diversity and strength.

Some food businesses are also involved with diversification of products which may not be in the food and beverage sector. An example of this is Hemp NZ which produces hemp-derived food products such as seeds and oil. It is also working in partnership with others to realise the value-add potential through hemp fibre – part of the 'other manufacturing sub-sector'. Instead of locating hemp fibre processing on the same site as food operations in the North Island or independently, they are working with an established yarn processing business in Christchurch to leverage opportunities in a completely different market.

Auckland and Christchurch host the highest number of **Meat manufacturing** businesses, while Auckland and Southland District have the largest workforce, followed by Matamata-Piako District.

Seafood manufacturing dominated in Auckland in terms of business count and employee count, followed by Marlborough, Thames-Coromandel District and Tasman. Invercargill had a significant number of businesses and employees.

Auckland had the highest number of businesses and employed the most people across the **dairy manufacturing** sub-sector, followed by South Taranaki, Hamilton, Waipa, Matamata-Piako district, and Palmerston North. Christchurch had the second highest number of organisations. These locations are stationed near major regional farming areas such as Waikato, Canterbury, Southland and Taranaki.

In 2019, Auckland had the highest number of businesses, followed by Christchurch City in **fruit and vegetable processing**. While Marlborough District, Tauranga, Gisborne and Hastings had a significant number of employees there were fewer businesses. Apples and pears are grown in Hawke's Bay and Nelson, followed by Central Otago and South Canterbury, which aligns similarly to where the larger centres or districts Fruit and Vegetable Processing facilities are found.

Oil and fat manufacturing is mostly found in Auckland, followed by Tauranga, Selwyn District and Far North District.

Grain mill and cereal product manufacturing activity is predominantly occupied in Auckland, followed by Christchurch City. Most wheat in New Zealand is grown in the Canterbury region. Many of the large cereal manufacturing organisations are located in Auckland.

Auckland, Christchurch City, Dunedin and Hastings are where majority of the employees and businesses are located for **bakery product manufacturing.** This coincides with where grain mill manufacturing is located.

Sugar and confectionery manufacturing activity is predominantly in Auckland, Christchurch City, Queenstown-Lakes District, and Tararua District. There is more regionality in comparison to other sub-sectors within food and beverage manufacturing.

Other food product manufacturing activity is spread across the country. Auckland followed by Christchurch City and Wellington City had the highest number of businesses and employees.

Beverage manufacturing is predominately based in Auckland, followed by Hastings District. It is notable that beverage manufacturing is also strongly anchored in the South Island, including activity in Marlborough District, Christchurch City, Tasman, Hurunui, Central Otago, Queenstown-Lakes District, and Dunedin.

Cigarette and tobacco product manufacturing is only found in Christchurch City and Lower Hutt City.

5.5. Data gaps

A wide range of data gaps and unknowns were apparent for the food and beverage sub-sector. In developing the data sets, a lack of resolution in emissions data resulted in uncertainties for specific categories of goods, such as fruits and vegetables, bakery products, oils and fats. A lack of granularity in production data similarly led to a sub-optimal mapping between the emission intensity and the relevant sub-sector. The lack of New Zealand specific emission intensities meant that we had to use proxy data from other regions, which are likely to give rise to inaccuracies. Location data and the ability to map emissions for sub-sectors has been valuable in developing our understanding. However, in many cases, we were unable to differentiate between manufacturing locations and head-offices, meaning that there may be an unfair allocation of emissions to Auckland, where many businesses have a head office. We identified further data gaps related to waste streams associated with packaging of goods in the food and beverage sub-sector. We were also unable to fully resolve the differences between impacts associated with attributional and consequential methodologies.

5.6. Stakeholder perspectives

A consensus view from participants in the workshop and interviewees was that while the significant export of dairy products and the substantial import of feed for livestock were anticipated, the scale of these flows surprised them, sparking discussions about the accuracy and definitions used in the data presentation. There was confusion regarding the definitions of production and consumption emissions, suggesting a disconnect between the terminology used in the data/mapping and industry expectations.

The granularity of data on dairy production, including detailed insights on inputs like imported feed and emissions, was identified as particularly interesting. It provided a valuable lens for understanding sector-specific impacts, despite the high greenhouse gas emissions associated with dairy and meat products not being surprising, as these are known industry impacts.

A notable gap was the lack of data on waste and by-products, especially in sectors like wine and juice manufacturing, where significant waste streams exist. Additionally, the impact of imported goods on emissions was seen as a potential data void. Suggestions for acquiring this missing data included engaging with specific industry groups, leveraging existing lifecycle assessment studies, and consulting government and industry reports, emphasising the importance of end-to-end value chain data.

Opportunities for reducing emissions and improving waste utilisation through better management of by-products were discussed. There was interest in shifting feed sources for aquaculture and livestock to reduce reliance on imported feeds with high emissions footprints. A fundamental need identified was clearer, more up-to-date data to inform decision-making, including a deeper understanding of supply chain emissions, waste streams, and the potential for circular economy practices within the sector. Collaboration across the industry to standardise data collection and reporting was also highlighted as a need.

Sector-specific practices and challenges

- **Waste and recycling management:** Waste and recycling practices, such as the reuse of spent grain as animal feed, reflect a symbiotic relationship with the agriculture sector. Challenges include managing waste yeast and hops and seeking more circular outcomes through initiatives like composting and improving trade waste management.
- **Emissions management:** The discussion around Scope 1, 2, and 3 emissions revealed efforts to standardise data collection and the challenges of obtaining meaningful supplier reporting. Commitments to reducing emissions through operational decisions, such as choosing suppliers based on their environmental practices, were noted.
- **Manufacturing processes and environmental impacts:** Insights into brewing processes highlighted circular approaches to waste and energy use, from sourcing materials using environmentally friendly methods to efforts to reduce water waste and improve packaging recyclability.
- **Collaboration and innovation for sustainability:** The potential for collaboration with other sectors and technology to foster a circular economy was discussed. Challenges in measuring and managing waste and byproducts were acknowledged, along with exploring sustainable packaging options and integrating renewable energy into production processes.

5.7. Additional analysis

5.7.1. Dairy product manufacturing

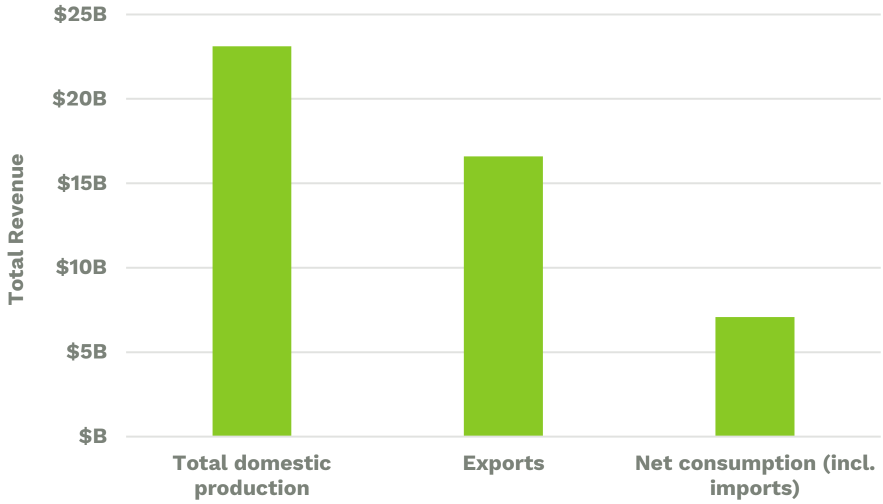

Figure 23 Dairy product manufacturing versus exports

We see that within Dairy manufacturing there is a large export market. As mentioned in the GHG Emissions Section and explored in Figure 22, we see that this makes a large difference to the overall consumption-based emissions.

Within dairy product manufacturing, production-based emissions are largely from plant energy requirements. EECA's Energy End Use Database (EECA, 2023) provides some insight into the sources for these emissions and where material decarbonisation opportunities may exist. As evident in Figure 24, most of the dairy product manufacturing energy consumption requirements are met by fossil fuels: natural gas (44%) and coal (40%). There is some electricity and other renewable fuel use, but these are currently small in comparison.

Low temperature heat for water, space heating, and process requirements (<100°C) and intermediate-temperature process heat (100-300°C) make up most of the energy demand, for processes such as **pasteurisation, evaporation,** and **spray drying**. Electrification of these processes, or replacing with alternative fuels like biomass, would cause a steep reduction in the production-based emissions of the dairy manufacturing sector.

Several projects of this nature are already underway, including:

- Mataura Valley Milk's world-first fully electric dairy factory (EECA, 2023)
- Fonterra's biomass boiler at Waitoa (Fonterra, 2022)
- Open Country Dairy's electrode boiler at their Awarua site (EECA, 2021)
- Synlait's electrode boiler at Dunsandel (Synlait, 2019)

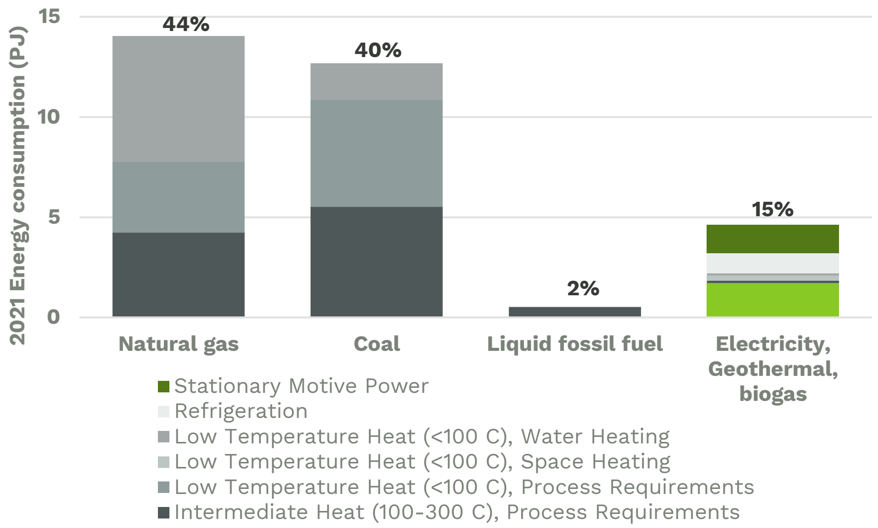

Figure 24 Energy use (petajoules, PJ) by fuel and process, dairy product manufacturing, 2021 (EECA EEUD)

Beyond the manufacturing sector itself, reducing supply chain emissions is more difficult as the primary input to dairy is the agriculture sector. Agriculture is challenging to decarbonise, as the current technologies available for reducing emissions from livestock like cows are limited and largely ill-suited to NZ's pastoral farming systems.

However, there is ambition across government and business to improve emissions outcomes from agriculture, including:

Fonterra's ongoing support to its farmers through bespoke emissions profiles. Farm Environment Plans and a Co-operative Difference payment (supported, and recently increased, by Nestlé) to reward and recognise farmers who meet sustainability targets, 83% of farmers currently qualify for these payments. Fonterra also invests in research and development initiatives such as Kowbucha to reduce methane production in cows. (Fonterra, Climate Change, 2023)

He Waka Eke Noa, a partnership between government, the primary sector, and iwi/Māori to equip farmers and growers to measure, manage, and reduce on-farm agricultural greenhouse gas emissions and adapt to climate change. Reporting of farm-level emissions will start in Quarter 4 of 2024 (Beehive, 2023)

As part of COP28, the New Zealand government signed an international agreement committing to sustainable agriculture, resilient food systems and climate action (COP28, 2023)

Further up the supply chain from agriculture is the fertiliser required for crops that dairy cattle depend on These are produced by the chemicals and refining industry which is itself a high emitter and significant user of natural gas for production. In New Zealand, Ballance Agri-Nutrients is working to decarbonise the manufacture of ammonia-urea at its Kapuni in site in Taranaki, with ambitions to reduce manufacturing emissions by 90% in the next ten to fifteen years. The Kapuni plant is the only domestic producer of nitrogen-rich fertiliser, GoClear (Ballance Agri-Nutrients, 2023).

Another area where progress is being made in decarbonising supply chain emissions is in transport. For dairy manufacturing, pilots are underway in New Zealand to electrify the milk tanker fleet.

For example:

- Fonterra's Milk-e battery swap technology is trialing on milk runs out of Fonterra's Waitoa plant (Fonterra, 2022).
- Mainfreight is trailing electric trucks (Wannan, 2022).
- The Kotahi collaboration between Fonterra, Silver Fern Farms and logistics partners such as Maersk is reducing the environmental impact of global goods transportation (Kotahi, 2023).

Because of these interdependencies, a multi-faceted approach is required to reducing supply chain emissions from the dairy manufacturing sub-sector.

5.7.2. Other food and beverage manufacturing

EECA's Energy End Use Database (EECA, 2023) also provides some insight into the sources for production-based emissions in the other food and beverage manufacturing sub-sectors through energy use. The EEUD does not break down energy consumption trends into the same sub-sector levels used in this project. Therefore disaggregated insights are limited at this stage of the project. Figure 25 and Figure 26 illustrate the 2021 energy demand by process and fuel for 'Meat product and seafood manufacturing' and 'other food manufacturing (excluding meat, seafood and dairy' respectively.

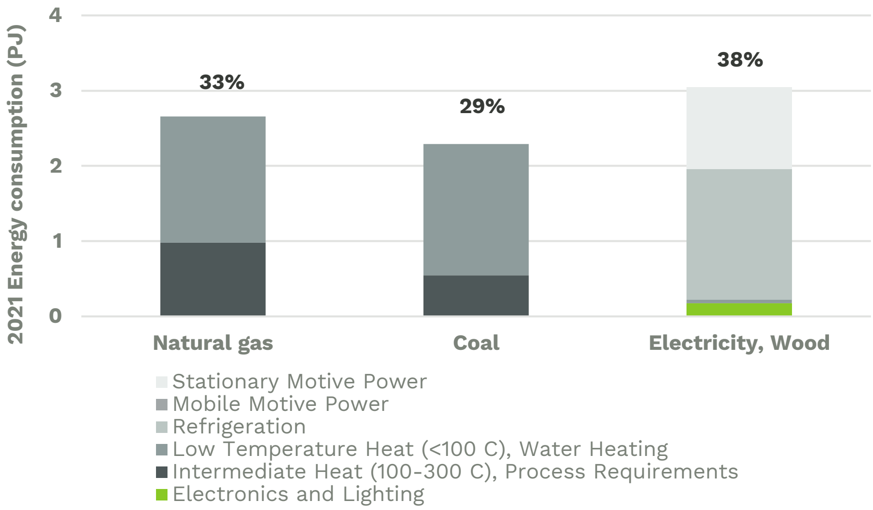

Figure 25 Energy use (petajoules, PJ) by fuel and process, meat product and seafood manufacturing, 2021 (EECA EEUD)

Similar to dairy product manufacturing, other food and beverage manufacturing has a heavy reliance on natural gas and coal for low and intermediate temperature heat. For meat product manufacturing, these energy uses can be for processes such as cleaning and sterilisation of equipment, rendering of animal by-products, and the making of speciality products such as small goods and cured products (MBIE, Meat and Meat Product Manufacturing Fact Sheet, 2018). Other uses in other sub-sectors include cooking with industrial ovens, steam and hot water production, hot smoking, pasteurising, sterilising, roasting, tempering and drying etc.

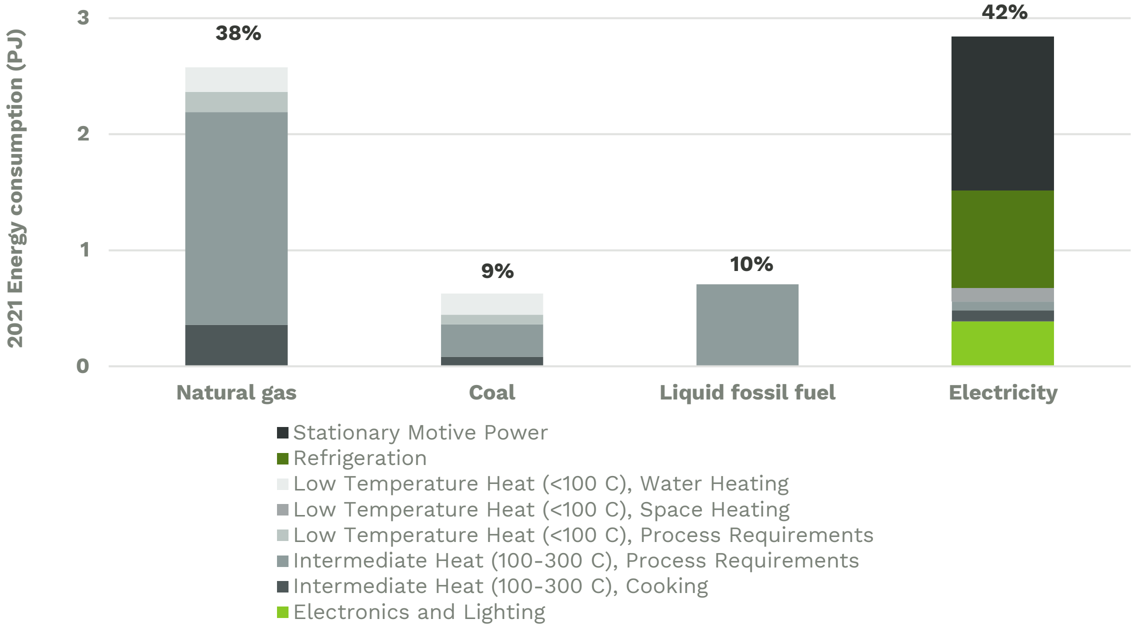

Figure 26 Energy use (petajoules, PJ) by fuel and process, other food manufacturing, 2021 (EECA EEUD)

As with the dairy sector, there are opportunities to decarbonise processes with lower temperature requirements by displacing coal and natural gas with electric or renewable alternatives.

Several projects have been supported by GIDI co-funding to decarbonise food and beverage manufacturing, including those listed below (EECA, Approved GIDI projects, 2023). Given the application criteria required by the GIDI programme, it is highly likely that these projects would not have progressed without the co-funding due to funding/financing challenges:

Meat product manufacturing

- AFFCO – energy efficiency, coal boiler replacement with electric boiler, biogas recovery to use as fuel
- Alliance – heat pumps, energy optimisation, mechanical sludge drying
- ANZCO – electric boiler and high temperature heat pumps
- Blue Sky Meats – high-temperature heat pump
- Auckland Meat Processors – high-temperature heat pump

Other food and beverage manufacturing

- Cedenco Foods NZ – steam recovery, energy efficiency
- Coca-Cola Europacific Partners – decarbonisation pathway including electric boilers and forklifts
- Lion NZ – boiler electrification
- McCain Foods – biomass boiler, heat recovery, pulsed electric field

Our initial research suggests that when considering opportunities and challenges to reduce emissions in food manufacturing, a sub-sector by sub-sector approach may be required due to the varying processes used in each sector. While there are commonalities (e.g.

natural gas and coal use in low- and intermediate-temperature heating), how these are applied and implemented can vary for specific manufacturing techniques.

Some of this sector-specific work has been commenced by EECA through their Sector Decarbonisation Programme (EECA, Sector Decarbonisation Programme, 2023). Through the programme, EECA collaborates with sector associations and technical experts to connect businesses with global innovation and provide best practice guidance at a sector level. Sector guidance is provided across five steps:

1. Increase engagement and awareness
2. Measure emissions and set targets
3. Optimise equipment and improve processes
4. Reduce energy demand
5. Switch to renewable energy.

EECA have published sector guidance on the following food and beverage sub-sectors, with more expected in the near future: beer brewing; coffee roasting; covered cropping; and wine.

This type of sector guidance is expected to be particularly useful to SMEs who may not have a dedicated energy/decarbonisation capability and its rollout across other sectors may be an opportunity to progress further.

5.7.3. Indicative resource input and output flows within and across sub-sectors

This table is representative of qualitative resource flow scan early observations made in November 2023 from rapid desktop research on ANZSIC Level 4 product resource and waste flows. Sense-checking of this information was to take place through future engagement. However as this did not take place, the information should be considered indicative only. Some instances of outputs currently occur offshore but they have been included in this table for consideration for circular opportunity e.g. bagasse.

The table provides some insight into internal connections with resources moving within food and beverage and also how outputs may become direct inputs into different manufacturing sectors. Of note, although resource flows may not be identified in formal waste and diversion reporting, they may be well established in the business practice and should be highlighted as existing circular practice. Further work is required to verify and quantify these connections.

Resource flows
Food + beverage

	Meat	Seafood	Dairy	Fruit + vege	Oil + fat	Grain mill	Bakery	Sugar	Other	Beverage	Cigarette + tobacco	Food + Beverage	Chemicals + refining	Plastics + rubber	Metal + metal products	Paper + wood	Machinery + equipment	Other
	EXISTING OUTPUTS (ANZSIC LEVEL 3)											EXISTING INPUTS (ANZSIC LEVEL 2)						
Damaged protective gear	●	●	●	●	●	●	●	●	●	●	●							
Damaged tools + equipment	●	●	●	●	●	●	●	●	●	●	●				recycled scrap metal			
Gumboots	●	●	●	●	●	●	●	●	●	●	●							
Pallets	●	●	●	●	●	●	●	●	●	●	●					firewood, planter boxes		motorway planting mulch
Bones	●	●										stock, gelatine, stock feed, pet food	fertiliser	plastic polymer				
Rendering	●											gelatine	bioenergy, hyaluronic acid, suplhate,					
Tallow	●											tallow	diesel, skincare					
Hides	●																	textiles
Wool trimmings	●																	textiles
Heads and legs	●											pet food, stock feed	fertiliser					
Chicken feet	●											chicken feet						
Proteins	●	●											peptone, pharmaceuticals					
Feathers	●																	pillows, duvets
Ash	●												natural fuels					
Marine trimmings		●										fish oil, pet food	pharmaceuticals,					architectural tiles
Mussel shells		●											fertiliser, water					
Salmon pens + fishing nets		●																bird netting,
Proliq			●									stock feed						
Whey			●										industrial ethanol					
Waste activated sludge		●	●										fertiliser					
Defective milk products			●										heat, energy,					
Fruit + vege (seconds)				●								fruit + vege						
Seed / seed husk					●	●						equine meals, stock						
Non-consumable oil					●								crop oil					dust supressant
Barley						●						chicken feed						
Straw						●							mulching, animal bedding, compost					
Bread offcuts							●					breadcrumb, beer						
Sugar								●				bee feed						
Molasses								●				stock feed						
Filter cake								●		●			fertilising					
Sugar slurry								●					soil supplement					
Bagasse (cane fibre)								●					biofuel	sugarcane plastic, compostable				
Potato starch									●			stock feed	biosurfacants, soaps, shampoos, bioethanol	compostable packaging		paper		
Spent grain										●		stock feed, crackers						
Yeast slurry										●			ethanol					
CO²										●		CO²						
Hop residue										●			compost					
Broken glass			●							●								pothole filler
Damaged screw caps										●					recycled scrap metal			
Pomace										●		dairy feed	soil conditioner, mulch					
Seeds										●		grapeseed oil	ground medium					
Grape marc										●		cattle feed						

This table is representative of early observations made in November 2023 from rapid desktop research on ANZSIC Level 4 product resource and waste flows. Sense-checking of this information was to take place through future engagement. Some instances of outputs currently occur offshore but have been included in this table for consideration for circular opportunity e.g. bagasse

Figure 27 Food and beverage resource flow study

5.7.4. Insights from wider research programme

Research conducted as part of wider MBIE circular economy research work by The Connective, ARUP and Project: Moonshot identified the following barriers to and enablers of opportunity areas in the food and beverage sector for a more circular economy:

Barriers:

- Limited focus on upstream – inputs and design
- Investment and support flows into conventional food production
- Export-orientated food sector, but poor domestic food sovereignty
- Dependency on unsustainable imported inputs – fertiliser and stock feed (e.g. PKE)
- Demands of domestic consumers out of sync with demands of global markets in the US and European Union
- Limited coordination between policies and funding and between different actors in food and beverage.

Enablers:

- Global and national regulatory pressures
- Global consumer demand for transparency in food value chain
- Global consumer demand for products created from sustainable, chemical-free ingredients and inputs
- Increased support for R&D
- Trend towards localism - intersect between local more resilient food systems and health
- Agriculture's loss of social licence to operate based on growing awareness of the disconnect between 'green' image of New Zealand food system and reality

Opportunity areas:

- Upstream innovation - Increase R&D and innovation in upstream segment of food value system to reinforce New Zealand's international competitive position and protect natural capital
- Meta-network - Cross-sector participatory meta-network of food system actors to create efficiencies and support the transition to low-emission, regenerative and ethical food production
- Real-time traceability – Increase transparency and traceability to meet consumer demand and global regulatory frameworks
- Place-based resilience - Develop place-based, circular food systems to improve resilience and food security

For this project, it is important to acknowledge that food and beverage manufacturing fits within a wider system, and manufacturers are a critical conduit between food producers, retailers, and consumers.

5.8. Examples and case studies

The following case studies identify specific examples of circular practices in NZ currently. The identification of these examples occurred during the desktop research phase.

5.8.1. Case Study: Sawmill Brewery

Sawmill Brewery is an independent NZ-owned brewery and restaurant run by a small team in the North Auckland region of Matakana. The brewery is piloting decarbonising through optimisation and fuel-switching, which led to the installation of carbon recapture systems. This allows the brewery to capture CO_2 produced in the fermentation for use in beer production. Additionally, spent grain is diverted to local farms or composted on site and refilling of glass flagons has been set up for consumers buying direct, incentivised by price (Sawmill Brewery NZ, 2023).

5.8.2. Case Study: PolyNatural vine clip

PolyNatural, based in Christchurch, makes vine clips from biodegradable polymers and waste materials sourced from wood processing. They are designed to replace traditional plastics clips that are used to fix bird and pest nets on vineyards. A research partnership between Scion and PolyNatural was set up to commercialise the product and set it up to export. The wood waste is fermented by micro-organisms and then formed to shape the clip that can fully degrade in the right soil conditions (Scion, 2023).

5.8.3. Case Study: Dunedin Craft Distillers gin and vodka

Offering gin and vodka, the Dunedin Craft Distillers make use of bread and bakery waste. Working with Kiwi Harvest, a national food-reuse organisation, the company identified sources for bread and bakery products destined to landfill. The waste products are combined with water and malted barley to create a mash that is fermented, distilled, and filtered to create a base spirit. In the first year of operation, four and a half tonnes of bread and bakery waste was turned into 1,400L of spirits. Next steps include upscaling the production (Griffin, 2022).

5.8.4. Case Study: Rutherford & Meyer crackers

Based in Lower Hutt, Rutherford & Meyer produce a cracker made from the spent grain of local breweries. The spent grain is delivered wet to their factory where it is dried, ground, and made into food products. Their upcycled product contains between 12-40% spent grain (Noon, 2022).

5.8.5. Case Study: Sealord and Motueka recycled fishing nets

Commercial fishing nets at end-of-life are shipped to Spain to be repurposed for other products, such as mussel farming ropes. This initiative is an outcome from Sealord's efforts to find a feasible alternative to the nets being sent to the regional landfill. Motueka Nets can recover polyethylene ropes for farm use and steel for recycling, before the nets are sent overseas. Previously, there was unsuccessful trialling of repurposing the nets as silage pit covers, and riverbank plants (Nelson Mail, 2023).

5.9. Sub-sector conclusions

The food and beverage sector in New Zealand represents a significant part of the advanced manufacturing landscape, 32% of GDP, provides considerable employment, and attracts the highest percentage of foreign direct investment of the sub-sectors studied. Eighteen percent of manufacturing businesses in Auckland were observed to be in the food and beverage sector, with other regional focal points linked to fruit and vegetable processing in areas such as Gisborne and baked goods and meat in Canterbury. A recent surge in investment has revolved around the growth of the dairy sector, particularly the production of milk powder, representing a robust international demand for New Zealand exports.

Our top-down analysis identified that the dairy industry accounted for 82% of the production-based food and beverage sector emissions, totalling 3,037 $ktCO_2e$ per annum. Meat production and seafood production followed at 560 $ktCO_2e$ and 157 $ktCO_2e$, respectively. Outside these key sub-sectors, New Zealand was found to be substantially reliant on imports, although our previous work indicated that it is largely self-sufficient in fruit and vegetables.

Our top-down data also highlighted the relatively high emissions intensity of the dairy sector within the food and beverage sub-sector and suggested that a significant component of these impacts was linked to the consumption of fossil fuels as energy sources for manufacturing. This was supported by our bottom-up assessment which identified fossil energy use as the most substantial contributor during the manufacturing stage, with milk powder production being the largest user.

Our bottom-up assessment of the dairy sector identified that the largest share of emissions originated from animal-related sources, particularly enteric methane and manure management. Emissions related to land-use change were also substantial, as were transportation impacts linked to animal feed and the production and transport of fertilisers.

Regionally, the impacts from the food and beverage sub-sector were highest in Auckland (20%), followed by southern districts and regions in the Waikato—aligning with where much of New Zealand agriculture is located.

A wide variety of case studies and low-carbon initiatives was identified. The sub-sector was observed to have an ongoing reliance on natural gas and coal, but efforts to decarbonise the sector were apparent and included replacing coal boilers, emissions reductions linked to fertiliser use, and the electrification of transport. The decarbonisation of manufacturing requiring higher temperatures, such as spray-dryers, was considered a more significant challenge to address. From a waste perspective, a high potential for the reuse of residues, co-products, and by-products was identified, along with numerous examples, but we were unable to find sufficient quantitative data to assess these internal flows. Likewise, a strong linkage between the sector and packaging (both as material inputs and as waste outputs) was also identified, but further quantification is required.

6. Machinery and equipment sub-sector

6.1. Sub-sector overview

Although a highly strategic part of New Zealand's manufacturing landscape, machinery and equipment has been declining in importance over time, with its relative economic contribution trending down over the last few decades. *Westpac's 2021 Industry Insight* shows that in 2019 this was at 1.7% of GDP, down from 2.5% in 1989, reflecting the transition towards the service and digital economy (Clark, 2021). Exports in this sector have risen, but not as fast as the rest of the economy.

This sector is dominated by large players, especially in agricultural equipment, with most firms SMEs. Examples include: Fisher & Paykel Healthcare; Compac Sorting; Buckley Systems; Gallagher Security; Tait Communications; Moffat; Skope Industries; Scott Technology; Trimax Mowing Systems; Southern Spars, TruTest, Livestock Improvement Corporation, and TruScreen Group Ltd.

Imports significantly outweigh exports and domestic production – in 2019, this figure was more than twice the value of local revenue at $27 billion versus $13 billion. The most significant export market segments are in mechanical machinery, optical, medical and scientific equipment, and electrical machinery and equipment. When including production for domestic consumers, transport equipment also becomes important. NZ machinery and equipment manufacturers generally operate in niches that help counteract the challenges of operating in a small market.

6.2. Top-down assessment

The top-down emissions account for this sector shows an overview of production and consumption-based (including supply chain) emissions across different sub-sectors in advanced manufacturing. Further analysis of the sub-sector, including increased granularity, is provided through the bottom-up assessment. The top-down assessment follows an economic allocation of emissions across the industries a sector relies on to produce a marginal output – based on the national accounts input-output tables.

Machinery and equipment manufacturing in NZ is starkly different to food and beverage manufacturing, as detailed in the previous section. The production-based emissions for this sub-sector is dwarfed by consumption-based emissions. As an example, when accounting for the supply chain impacts of the motor vehicle and part manufacturing sub-sector, these emissions are roughly equivalent to meat product manufacturing, a significant export sector for NZ.

The difference is that these impacts come almost exclusively from imported goods. Data showing the small difference between consumption-based emissions with and without exported goods helps to confirm this.

Emissions from exported goods come from machinery and equipment produced locally in markets that NZ is competitive in, such as marine equipment or harvesting machinery. In general, these are produced from imported materials, meaning the supply chain emissions for production are more significant than the local impacts. Additional export-focused emissions come from re-exported products that were previously imported.

6.2.1. Greenhouse gas emissions

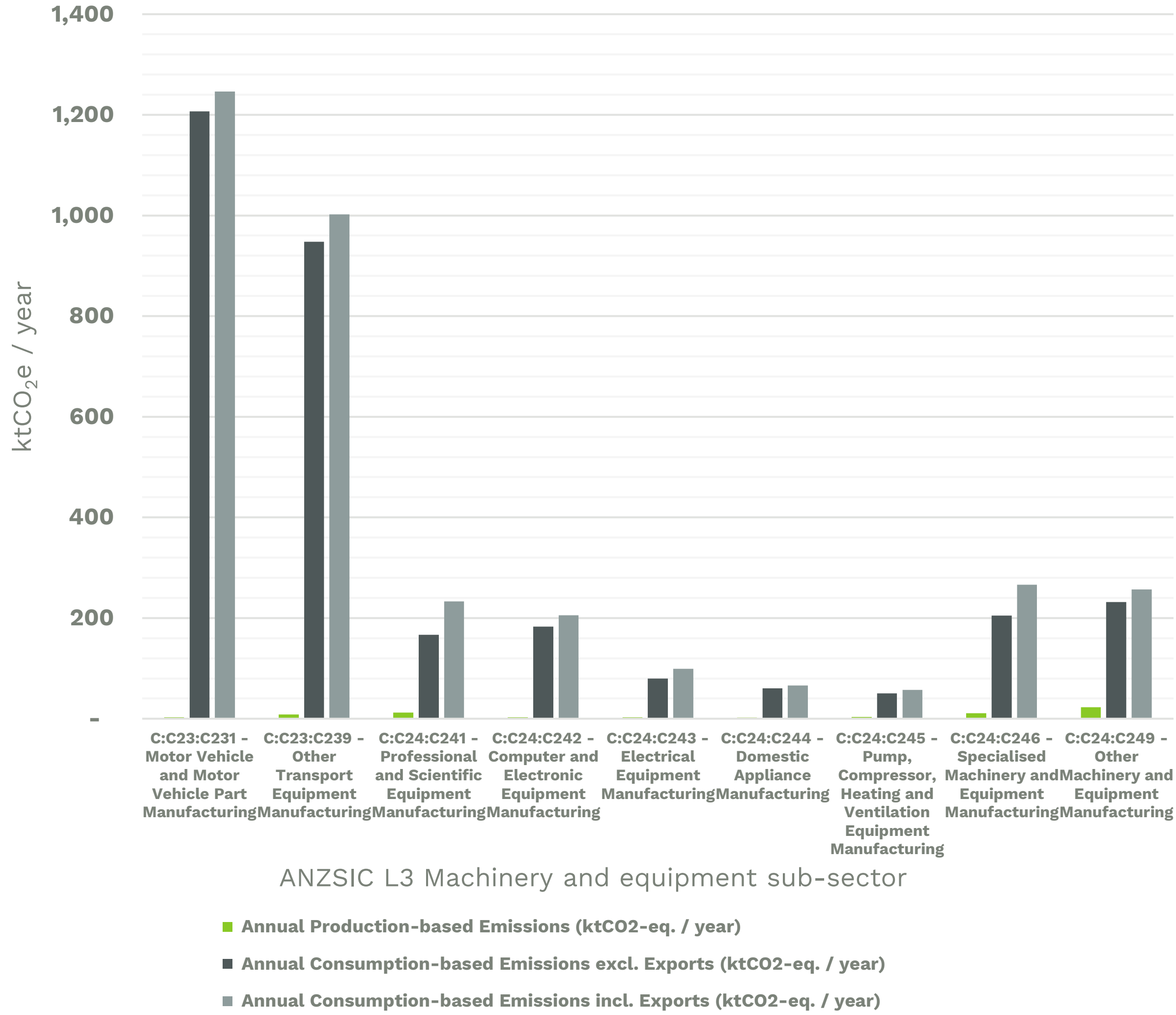

Figure 28 Annual production- and consumption-based emissions from the machinery and equipment manufacturing sector ($ktCO_2e$ / year), 2019 baseline

The difference between these sub-sectors is largely down to the difference in domestic production numbers, and import/export value. This is because of the granularity issues from one-to-many mappings when converting values to ANZSIC06, where many sub-sectors are allocated the same emissions intensity. Although not explored for this sub-sector specifically, sensitivity analysis has been conducted on a hybrid methodology that aims to address this issue. Refer to Sensitivity analysis, Section 13 for more detail on this.

Motor vehicles, parts, and other transport equipment are the largest emitting sub-sectors under machinery and equipment manufacturing, which is a result of a combination two things: higher consumption of these goods, and a much larger emissions intensity than other types of machinery and equipment, as shown in Figure 29.

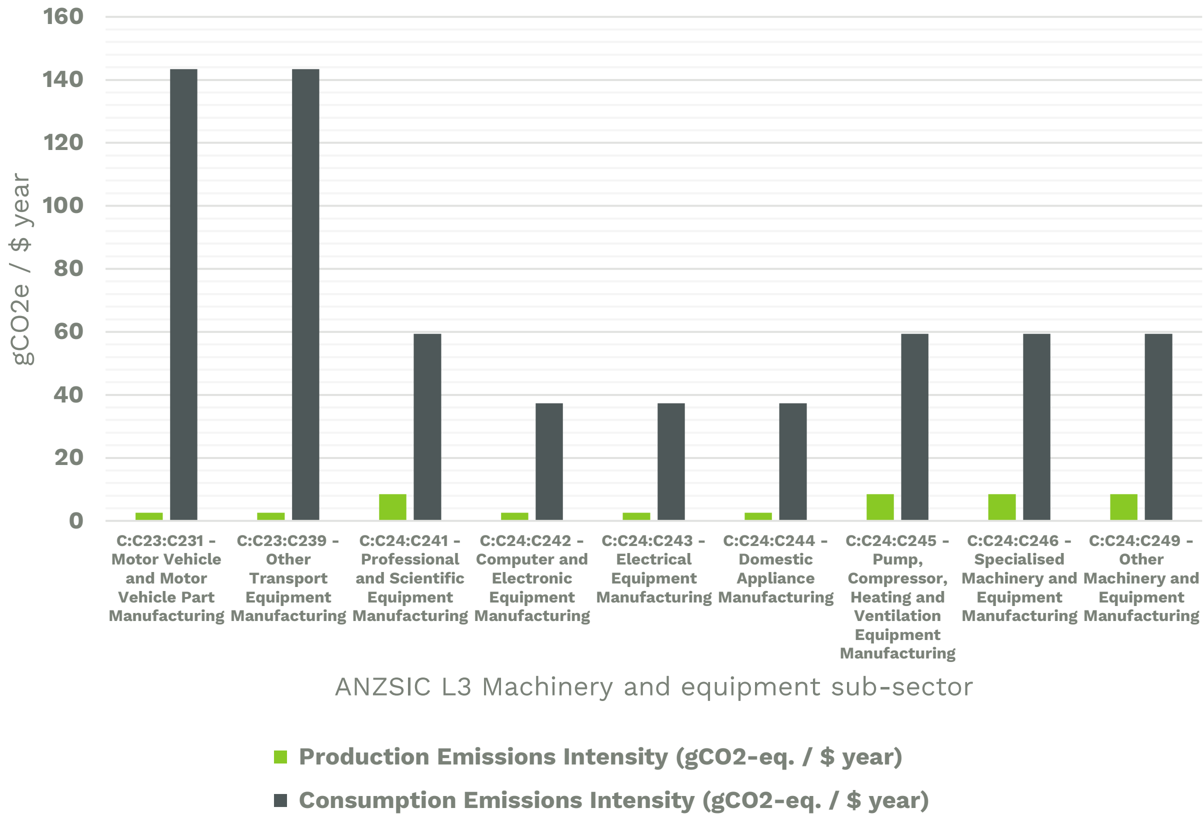

Figure 29 Production- and consumption-based emissions intensities for the machinery and equipment manufacturing sector (gCO$_2$e / dollar - year), 2019 baseline

The emissions intensities of these sub-sectors are low when compared to the food and beverage sector, even when supply chain emissions are included in the consumption-based numbers. On a production-only basis, this may suggest that investing in the machinery and equipment manufacturing sub-sectors would result in lower emissions for each dollar invested compared to alternative sectors. We note that these emissions are only calculated on a production basis, and whole-of-life emissions are not considered here.

Work conducted as part of Project 1 of MBIE's Circular Economy Research Programme suggested that linked strategies to reduce emissions could decouple the sector from import demands by enhancing the service life of vehicles, encouraging reuse and remanufacturing of parts, and utilising service-based models. Again, we note these strategies do not account for whole-of-life emissions, and that there has been no analysis comparing extending the life of fossil-driven machinery to newly-produced low-emissions technologies.

The value of this industry is very large ($4.86 billion), the second largest after food and beverage ($7.46 billion), but accounts for a much smaller share of emissions because of these low intensities.

The difference in local versus offshore production-based intensities (domestic production in New Zealand) is substantial. This data does not support the identification of a single cause, but we can infer a combination of factors may be influencing this. They could include the type of manufacturing in each sub-sector (e.g. the assembly of buses from imported parts versus manufacturing cars from scratch, which have different ANZSIC L4 codes but are aggregated at L3) or the highly renewable electricity grid in New Zealand compared to our key trading partner's grid's for this sector.

These dynamics suggest that targeting improvements in production-based emissions for this sub-sector may have a small impact when compared to other strategies such as targeting imported products. This is especially so when compared to local sectors with larger emissions footprints such as food and beverage.

Improving production-based emissions would have its own complications, in that these sub-sectors can have very large energy requirements for complex manufactured products, and there may not currently be enough renewable grid electricity to service these needs. To remain low emission compared to other sectors, it is important any new investment in this sector is supported by low emissions energy sources to differentiate the sector from other sectors which still have a large requirement for coal and natural gas. Considering the domestic market is small, there are still pockets of the country where machinery and equipment manufacturing is more active than others, as shown in Figure 30.

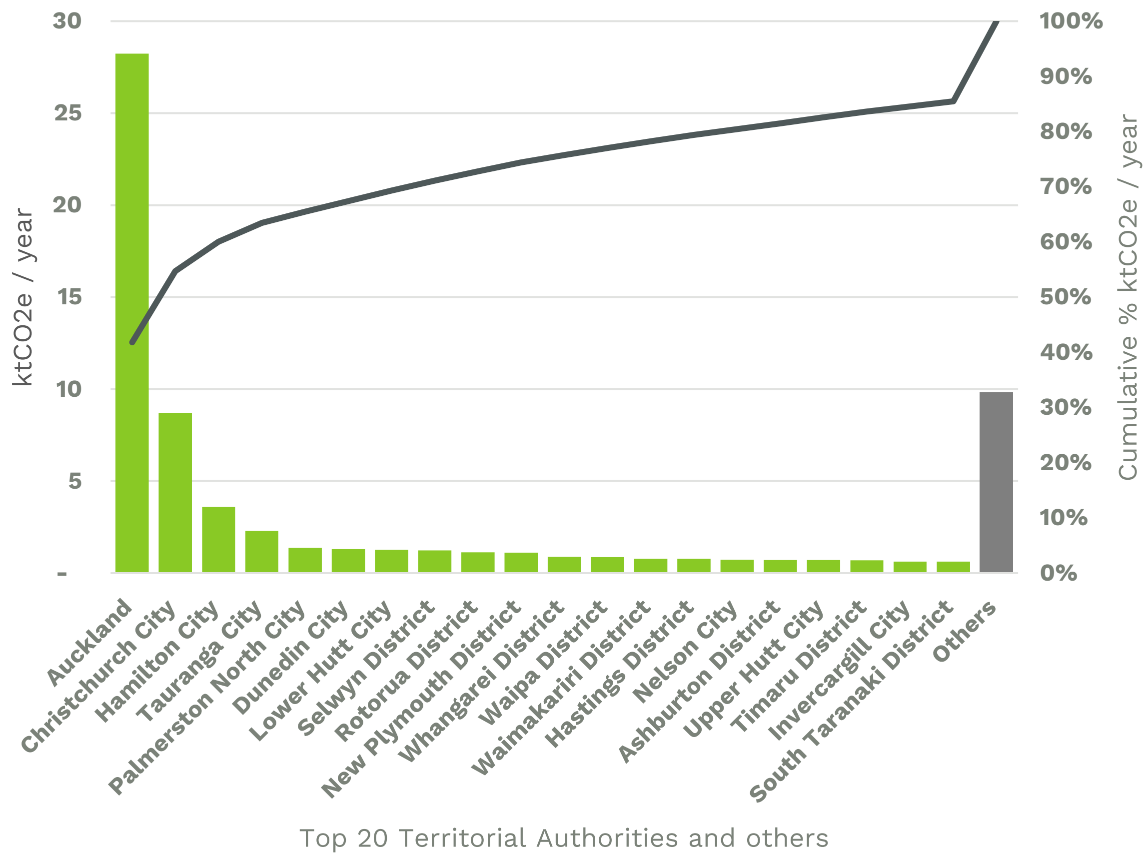

Figure 30 Annual production-based emissions from the machinery and equipment manufacturing sector across NZ territorial authorities (ktCO₂e / year)

Once again, we see Auckland being the largest contributor to this sector, with 42% of the total for the country. Christchurch and Hamilton represent the next largest portions of machinery and equipment manufacturing with a steep drop-off after that – showing other territories all have a very small contribution to the total. This could indicate SMEs scattered across the country working in niche industries, with most of the larger companies and producers being based in Auckland, Canterbury and the Waikato.

This steep drop-off after Auckland is different to the previous section on food and beverage where the next few regions still contributed significant amounts of emissions to the national total. This suggests machinery and equipment manufacturing is quite localised, which may lend itself to circular practices that are quite region-dependent.

Overall, from a top-down emissions perspective, machinery and equipment manufacturing is an import-dominated sector with a very small domestic presence – mostly concentrated in Auckland. Due to the very low production emissions this would be a suitable industry to invest in generally, as for each marginal unit of revenue created in the industry, the emissions footprint is much smaller than many alternative sectors. The localised nature of the sector also means implementing circular economy opportunities is possible, where by-products and co-products are better utilised within the sub-sector, and other sectors like metals and metal products.

6.2.2. Waste

Focusing on potential machinery and equipment manufacturing waste generation, the following associated streams are outlined in Table 5.

Table 5 Machinery and equipment waste characterisation by waste material composition, SWAP categories

	Machinery and equipment	Identified source examples
Organics	✓	From bio-based resource inputs
Cardboard and paper	✓	Packaging
Timber	✓	Packaging
Rubble/concrete (incl. cleanfill)		
Potentially hazardous	✓	Metal and chemical-contaminated cleaning outputs, e-waste, dust, oils and lubricants, cleaning liquids
Plastic	✓	Packaging
Metals	✓	Defective and corroded parts, offcuts
Textiles	✓	Personal protective equipment
Nappies and sanitary	✓	Personal protective equipment
Glass	✓	Defective parts, off-cuts, fibreglass waste
Rubber (incl. tyres)	✓	Tyres, defective machinery parts

Through qualitative resource flow scan activities, we were able to identify potential waste outputs associated with production. This was predominately related to the diverse types of materials involved in this sector. Machinery and equipment is associated with complex product design and manufacturing requirements, acknowledging that this may involve reliance on offshore production of parts and assembly activities within NZ. E-waste and vehicle-related waste are associated outputs at the consumer level. Although this is beyond the scope of manufacturing it is of relevance to producers and importers due to emerging product stewardship schemes in NZ.

6.3. Bottom-up assessment

6.3.1. Qualitative resource flows

Part of the resource and waste mapping for the machinery and equipment sub-sector included the development of material flow diagrams at ANZSIC level 4. These identify the key product, input resources, and output co-products, by-products, and waste products. It also identified opportunities for circular resource flows across ANZSIC levels 3 and 4. Sub-sector material flow diagrams completed to date include:

- C2451 Pump + Compressor (Figure 31)
- C2441 Whiteware Appliances (Figure 32)

These flow diagrams are shown on the following pages. Overall, this exercise has identified some key findings and opportunities.

- Unused, damage or no longer fit-for-purpose metals, as well as scraps, can be resold back to the metals industry for reprocessing (e.g. smelting, crushing, shredding) into raw materials for manufacturing operations both in New Zealand and around the world (Sims Metal, No Date)
- Repair, refurbishment, overhaul and rebuild services exist within the machinery and equipment sub-sector, through product stewardship and public recycling providers (Fujifilm, No Date)
- Advanced water reuse occurs using specialised selective membranes and ion exchange systems (Hydroflux Industrial, No Date)

Qualitative Resource Flows

C2451 Pump
+ Compressor

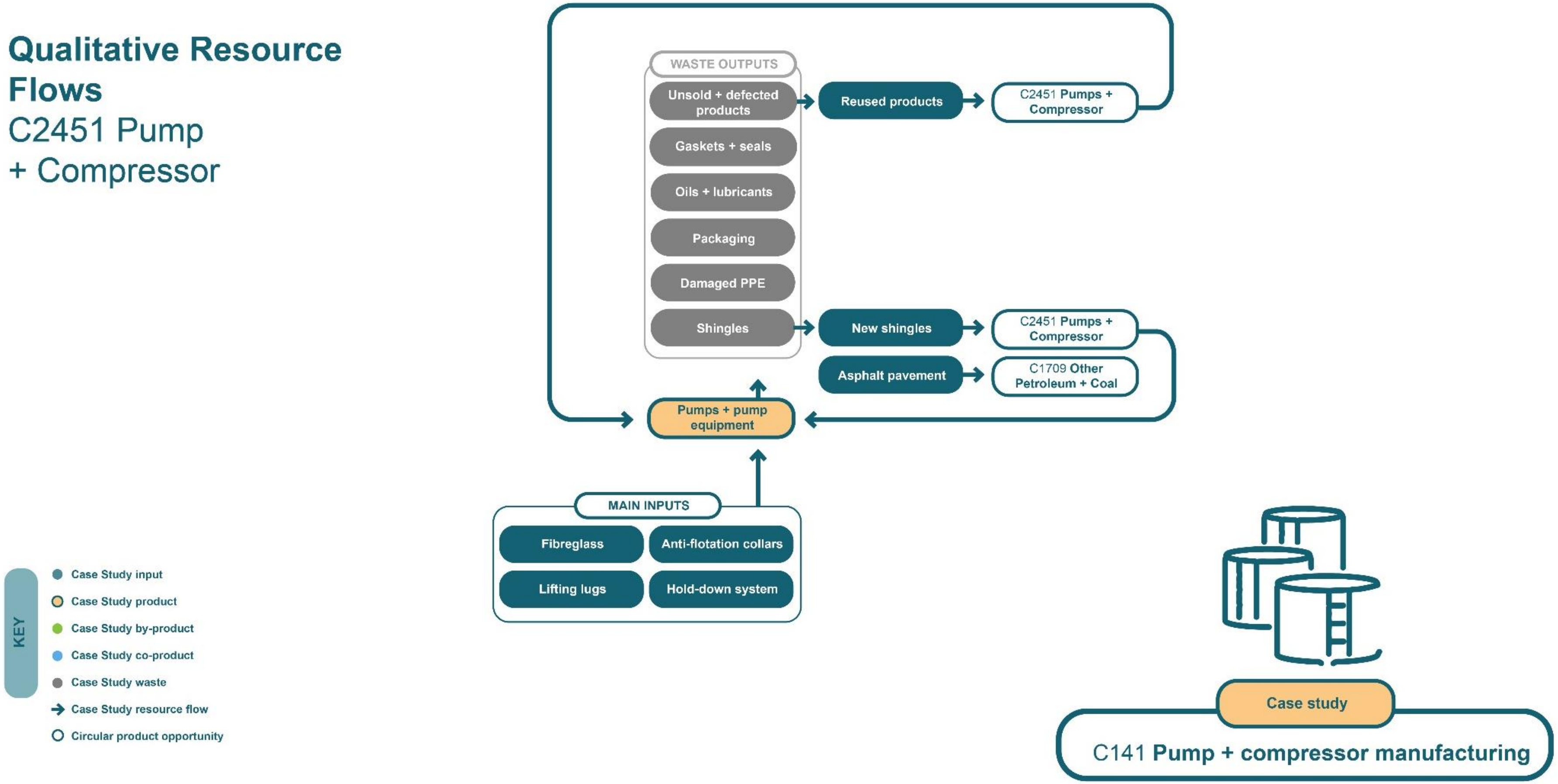

Figure 31 Resource flow map for Pump and Compressor manufacturing (C2451)

Qualitative Resource Flows
C2441: Whiteware Appliances

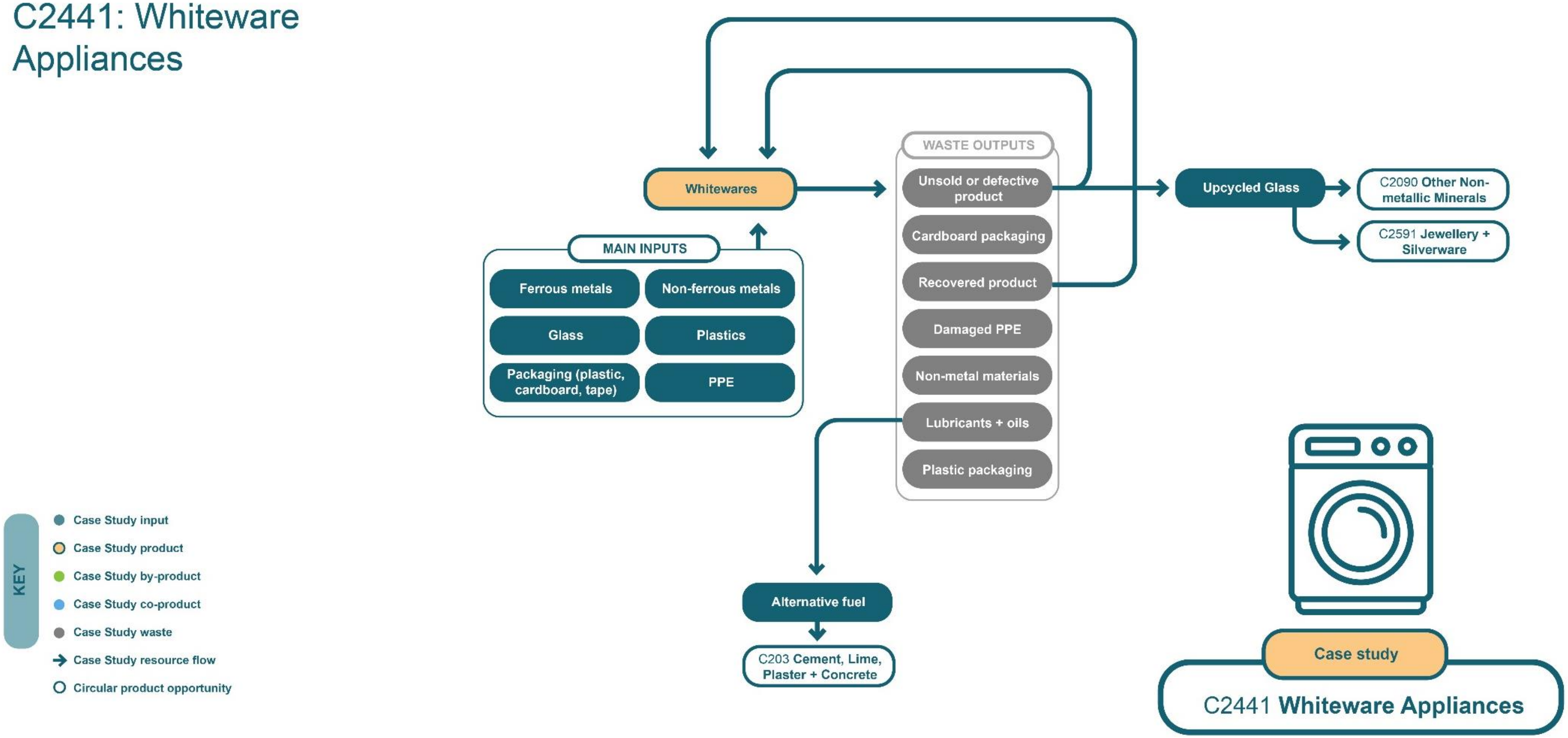

Figure 32 Resource flow map for Whiteware Appliances (C2441)

6.3.2. Key material flows

Machinery and equipment sector in NZ, 2019

Sources: National accounts
(million of NZD/year)

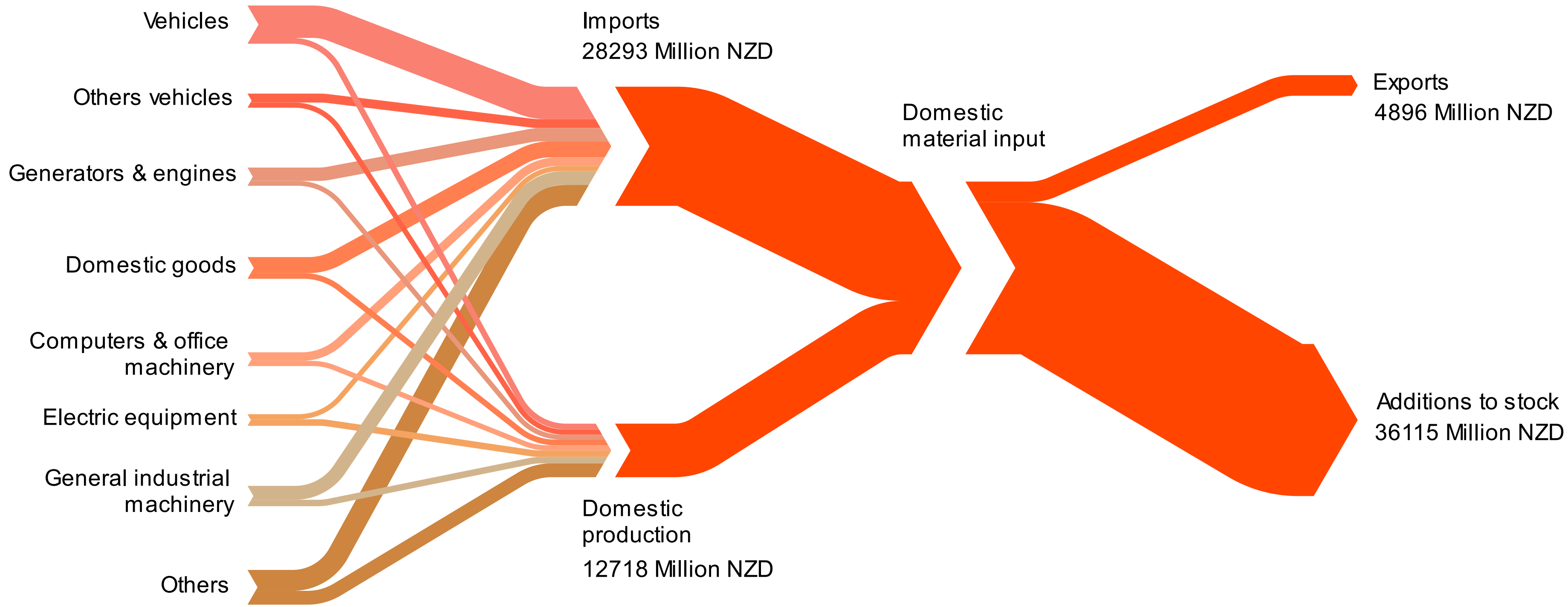

Figure 33 Economic flows associated with machinery and equipment imports into New Zealand in 2019 and subsequent flows into exports or stocks.

6.3.3. Hotspots identified

With reference to Figure 33, the following features were noted:

1. **Imports:** The sector is heavily reliant on imports, which amounted to $28,293 million. This suggests a substantial demand for foreign machinery and equipment, which domestic production does not fully satisfy.
2. **Domestic production:** The Sankey diagram indicates that the value of domestically produced machinery and equipment was $12,718 million in 2019. This level of domestic production demonstrates that while there is a dependence on imports, there is also a notable contribution of New Zealand's own manufacturing capabilities to the sector.
3. **Exports:** The exports totalled $4,896 million, which, while notable, is minor relative to the imports. This indicates that the sector is not a net exporter and may be focused on meeting internal demand or specialised machinery and equipment production.
4. **Additions to stock:** The value of additions to stock, potentially representing inventory accumulation, was $36,115 million. This is a considerable amount that suggests a build-up of machinery and equipment stocks within the associated sectors. These stocks will presumably stay in use within the New Zealand economy for some undetermined timeframe before being resold, exported, refurbished or scrapped.
5. **Flow diversification:** The diagram breaks down the imports and domestic material input into sub-categories such as vehicles, generators and engines, domestic goods, computers and office machinery, electric equipment, and general industrial machinery. This indicates a diverse range of machinery and equipment being handled within the sector. Of all of the categories, vehicles represented the largest share, followed by domestic goods, general industrial machinery and generators and engines. This suggests a strong consumer demand for imported vehicles and other domestic appliances, perhaps including garden equipment and tools.

6.4. Location

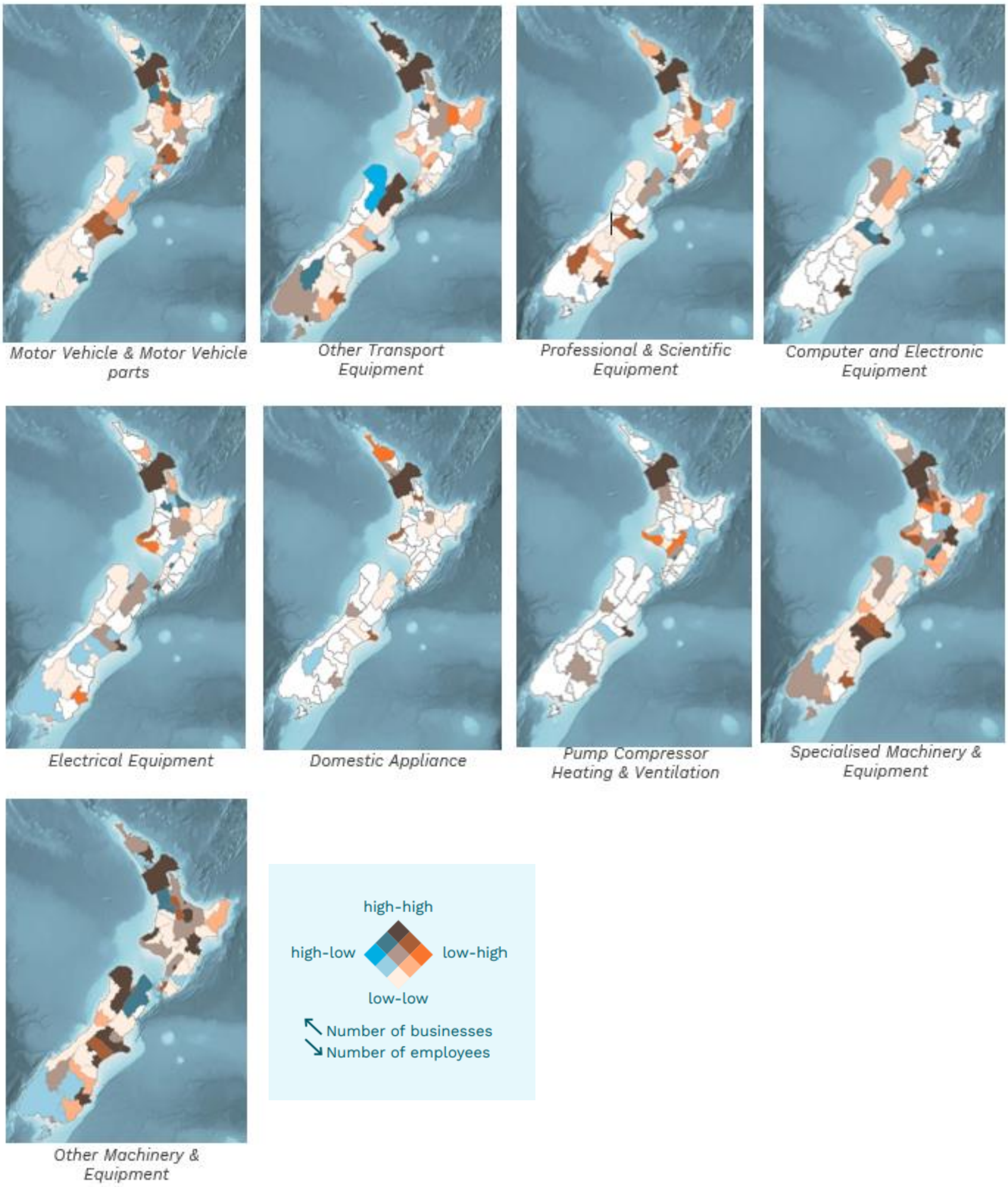

Figure 34 Manufacturing activity location – Machinery and equipment ANZSIC Level 3 by territories, 2019

Machinery and equipment activity is mainly located in Auckland, Christchurch, and Hamilton with a large spread of organisations across the country and associated with high number of SMEs. Motor Vehicle and motor vehicle part manufacturing activity is higher in Auckland, Christchurch, Wellington followed by Palmerston North.

6.5. Data gaps

A range of data gaps were identified associated with the machinery and equipment sub-sector. As with other sub-sectors, a lack of granularity in the data inhibited our ability to fully resolve some of the resource and emissions associated with the sector. Similarly, a lack of appropriate emission intensities and inadequate data on offshore emission intensities associated with imported goods will have resulted in inaccuracies in the data. A general lack of knowledge on the flow of stocks within the New Zealand economy was also noted. For example we do not know the age of vehicles in the New Zealand fleet or their likely replacement cycles, or the extent to which equipment is refurbished or resold within the internal market. A greater knowledge of stocks would enable a better understanding of the drivers for domestic demand. More broadly, a lack of knowledge of how to share data safely within a competitive market was raised alongside a desire to understand how to drive a greater level of repair within New Zealand to reduce the need for imports.

6.6. Stakeholder perspectives

Participants at the workshop were notably surprised by the scale of material flows, particularly the density of stock additions within New Zealand. This highlighted a significant issue that needs addressing domestically. The extensive reliance on imports presents potential challenges for the sector, including managing emissions from these materials and ensuring supply chain resilience.

The discovery of minimal production emissions juxtaposed with significant consumption-based emissions, especially from imported motor vehicles and transportation equipment, underscored these material flows' economic impact. This insight points to a deeper understanding of the sector's environmental footprint and economic implications.

A crucial gap identified was the lack of data on the lifecycle of products once added to stock, including usage duration and end-of-life pathways. The feasibility of internal data gathering within companies was discussed as a more practical approach than top-down methodologies, emphasising the role of motivated individuals within organisations in championing sustainability efforts.

The discussions revealed a potential for enhancing the sector's sustainability through remanufacturing, repairability, and design for disassembly. This approach could extend the service life of products and minimise environmental impacts. The concept of product-as-a-Service models, like Philips' ‘lumens per hour’, was highlighted as an innovative strategy to encourage the manufacture of durable, repairable, and recyclable products. The need for a multi-focused group on repair and commercial investment to bring innovative ideas to fruition was also noted, alongside the necessity for an in-house champion to gather and share data. Competition was seen as a potential barrier to effective data sharing.

Sector-specific practices and challenges:

- **Waste and recycling management:** The sector has a broad spectrum of practices, from innovative waste reduction and recycling to traditional disposal methods. The role of Industry 4.0 technologies in enhancing operational efficiency and waste minimisation was discussed, with collaboration within the industry seen as crucial for sharing best practices.
- **Emissions management:** The discussion did not address how the sector handles Scopes 1, 2, and 3 emissions. However, the potential benefits of adopting Industry 4.0 technologies for emissions reduction were mentioned, with a general awareness of sustainability issues within the sector highlighted.
- **Manufacturing processes and environmental impacts:** Insights focused on adopting Industry 4.0 technologies, including digital twins and AI, to improve operational efficiency and reduce environmental impact. However, detailed insights into raw material sourcing, energy use, logistics, and end-of-life processes were not extensively covered.
- **Collaboration and innovation for sustainability:** The potential of the bioeconomy and innovative applications like Mint Innovation's e-waste recycling technology were discussed. The need for improved stock management practices and exploring circular economy principles to reduce waste and enhance internal material use were also highlighted.

6.7. Examples and case studies

The following case studies identify specific examples of circular practices in NZ currently.

6.7.1. Case study: Fujifilm product stewardship

Fujifilm take back used machines, printer cartridges, drums, and fusers to be recycled, repurposed, or refurbished (Fujifilm, No Date).

6.7.2. Case study: NZ Steel electric arc furnace

Recycling is an option for defective or end-of-life machinery which cannot be refurbished or repaired. Scrap steel in NZ has been largely exported following the closure of Pacific Steel's arc furnace. The delivery of NZ Steel's new electric arc furnace will provide a local demand for scrap steel once more. The furnace will power the processing of steel with scrap steel collected from numerous sources, e.g. post-manufacture, construction, end-of-life, machinery, and post-consumer (NZAMR, 2023).

6.7.3. Case study: Cargill Enterprise personal protective equipment recycling pilot

Health and safety regulations require businesses to replace personal protective equipment (PPE) regularly. Factors such as logo removal mean that often PPE is sent to landfill. In Dunedin 2021, Cargill Enterprises trialled a PPE recycling programme that employed 80 people on a social employment scheme to conduct the time-consuming process of removing embroidered and screen printed logos (Kennedy, 2021).

6.7.4. Case study: Philips' technology-as-a-service in healthcare

Philips New Zealand actively advocates for technology-as-a-service (TaaS) in healthcare, highlighting the cost and waste benefits of lifecycle technology asset management (Philips, 2021). By subscribing to a healthcare equipment service programme, hardware and software is kept up to date and repaired due to remote equipment monitoring and preventative maintenance. This ensures potential waste is identified in advance, maintenance and operational efficiency of healthcare equipment is optimised (Philips, No Date).

6.8. Sub-sector conclusions

The machinery and equipment manufacturing sub-sector is known to have declined in New Zealand over the last few decades and now represents 1.7% of GDP, down from 2.5% in 1989. New Zealand manufacturing and exports in the sub-sector are now primarily driven by niche manufacturing. The sector is financially dominated by a few large players, with most firms being smaller. Auckland remains the most significant region with a diverse range of businesses. Other regions tend to be more specialised around agritech, oil and gas or electronics. Approximately 12,018 manufacturers were identified in this sub-sector, employing 83,556 people.

Due to the strong import dependence of the sector, our top-down assessment identified consumption-based impacts to be substantially higher than production-based impacts. The opportunity to influence the impacts of this sector will, therefore, be primarily driven by demand-based solutions that seek to extend the service life or utility of the products we import. Emissions avoided will be largely offshore.

Our bottom-up assessment highlighted that we imported $28,293 million of machinery and equipment in 2019 with a further $12,718 million of domestic manufacturing being supported by imported materials and components. A comparatively small $4,896 million of exports was observed, with $36,115 million flowing into stocks within New Zealand. Vehicles, domestic goods and engines featured prominently. The substantial flow of value in this sub-sector into stocks implies that these materials persist in our economy and support economic activity. A lack of data about where these stocks are, how long they are likely to persist and how they can benefit the New Zealand economy when they exit service, represents a substantial data gap that underpins attempts to plan for the longer term or to anticipate future demand.

Reuse, shared use, remanufacturing and recycling stand out as opportunities that may serve to create high-quality employment as well as substantially decouple the New Zealand economy from price volatility and other critical minerals risks. Our stakeholder engagement identified an interest in product-as-a-service (PaaS) models, modular and durable design, and a lack of confidence in adopting these models. An anticipated increase in onshore demand for used machinery and equipment was linked to the completion of New Zealand Steel’s electric arc furnace.

It was evident that New Zealand's machinery and equipment manufacturing is also highly dependent upon access to imported materials and components, meaning that the environmental impacts associated with these materials are also offshored. New Zealand must be mindful of these impacts and international initiatives that may decrease access or increase costs. A continuing focus on manufacturing high-quality, low-carbon and durable goods will likely be beneficial in differentiating our exports in line with international trends.

7. Wood and paper sub-sector

7.1. Sub-sector overview

The wood and paper sub-sector encompasses the production and manufacturing of products made of wood, including milled or dressed timber and engineered wood products. It also includes paper-based products including pulp, paper and paperboard, as well as products made from converted paper, including pulp-based sanitary products. Finally, printing and media reproduction is included in this sector.

The wood and paper sub-sector contributed 8.9% or $2,147 million towards national GDP in 2020. The manufacturing growth in GDP between 2018-2022 was 1.28%. The industry is focused almost entirely on Radiata pine, with only 10% of logs coming from other species. Harvest volumes have doubled since 2000 but processing capacity has stayed the same. As a result, exports of raw logs have quadrupled in this time to around 60% of the total harvest capacity. Raw logs and their initial processing are not included within this advanced manufacturing sector.

New Zealand has around 90 sawmills around the country, mostly located in the central North Island, with Otago and Southland providing the second highest number of mills in the country. This distribution reflects the locations of plantation forestry, with the largest volumes coming from large corporate owners. The market is highly concentrated, with 6 large mills producing over half of NZ's sawn timber.

Forests, sawmills, and secondary processors are typically located close to each other to increase efficiency, reduce costs related to transport and infrastructure and share heat and energy. There are currently four major pulp mills and a range of other processing companies that make products such as posts, packaging, plywood, MDF and wood pallets using sawmill products and logs.

Forestry and wood products are New Zealand's third largest export good, after dairy and meat products. This market is dominated by raw log exports but also includes processed wood products, which are considered here. Paper production volumes decreased over the past decade due to lower demand for newsprint, whilst pulp production has remained stagnant. Both these products have significant export contributions, with pulp (mainly used in cellulose fibre-reinforced boards) and paper exports at 62% and 50% of production, respectively (Westpac, 2018). Domestic timber production has also remained flat, with exports being geared back towards raw logs in the past few decades. China is the largest export market across the sector, with Australia, Indonesia and Japan being key trading partners. The sector overall has declined in relative importance over time, with production increases and output values not keeping pace with growth in the overall economy.

7.2. Top-down assessment

7.2.1. Greenhouse gas emissions

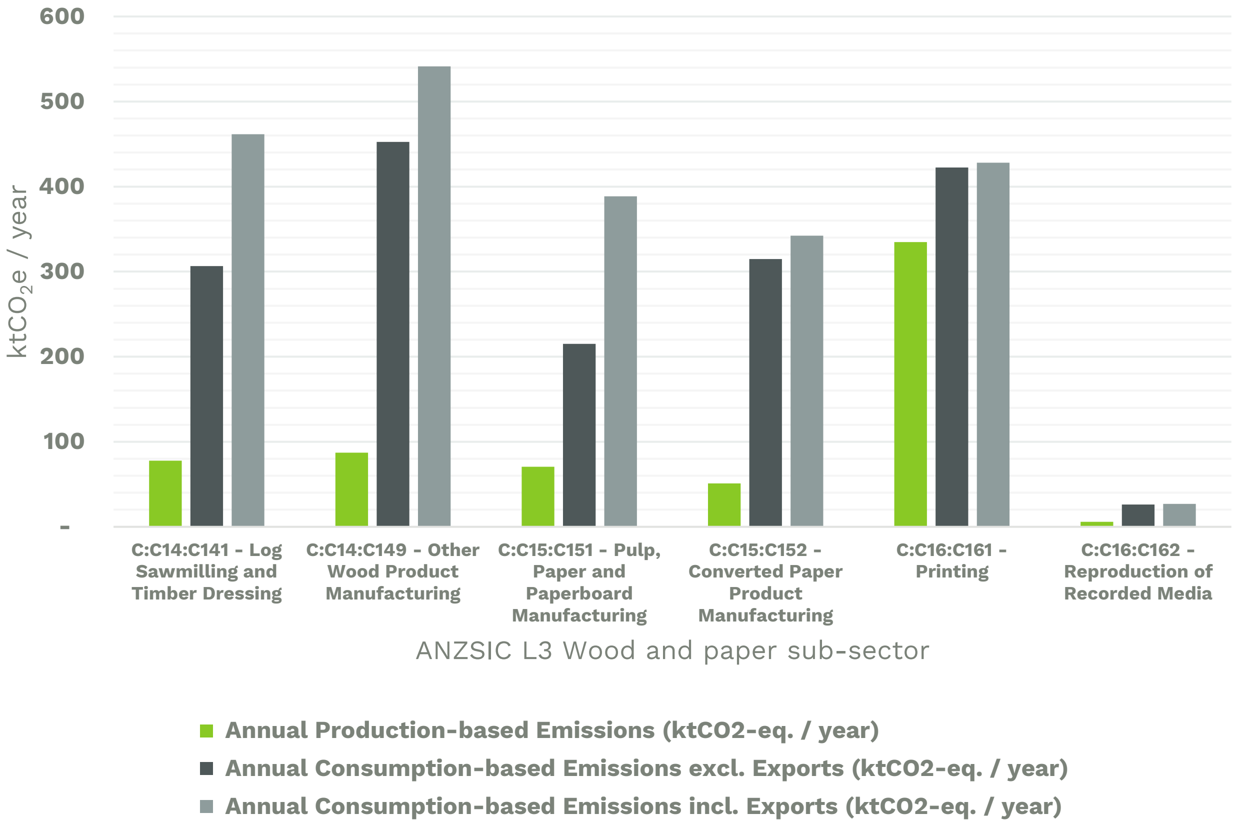

Figure 35 Annual production and consumption-based emissions from the wood and paper manufacturing sector (ktCO₂e / year), 2019 baseline

There is a wide range of outcomes within this manufacturing sector. Log sawmilling and other wood products each have a relatively small production-based emissions footprint but a much larger consumption-based figure. This may be due to most of the emissions being associated with the primary sector and forestry, with the actual manufacturing portion being relatively low emissions.

An additional factor is that the emissions included in the data set are fossil-based only, meaning that the biogenic emissions caused by burning biomass such as wood are not included. The high usage of biomass fuel for process heat in the wood and paper sector suggests this emissions data set only includes a small proportion of the total energy requirement for the sector, including from liquid fuels. This is methodologically correct, with biogenic carbon assumed to only enter the short-term carbon cycle and be rapidly taken back up by other vegetation, but used alone, fossil emissions may be misleading if used as a proxy for production activity across the sector.

The high proportion of consumption to production-based emissions likely has a different cause to other sectors – we suggest that for sawmilling and wood product manufacturing, this is not due to a high reliance on imported products but the impact of the wider supply chain, including the upstream forestry and transport sectors. The significant gap between domestic-only consumption and consumption including exported products suggests a large impact from exports and a large impact from exported products.

This same trend seems to continue for pulp and paper manufacturing but not for converted paper product manufacturing. This sector is much like previous import-driven sectors with large supply chain emissions and a very small production footprint, but with negligible exports. We note that proportionally, the converted paper products sub-sector exports very little compared to sub-sectors such as wood products and pulp and paper production. This could be due to the NZ export supply chain being geared to raw and intermediate products, the relatively low value-add of these products, and the higher economies of scale that international producers can achieve.

Printing is completely different again to the first four sub-sectors, with a very large production-based footprint and a very marginal increase to consumption-based emissions. This may indicate most of the emissions intensity of printing is the manufacturing process itself, rather than its supply chain. Additionally, we suggest this sector is likely only servicing domestic demand (primarily for the packaging and advertising sector) rather than any exports – much like cement, lime, and concrete products from the previous section. This thinking is in line with the results from the emissions intensities shown in Figure 36.

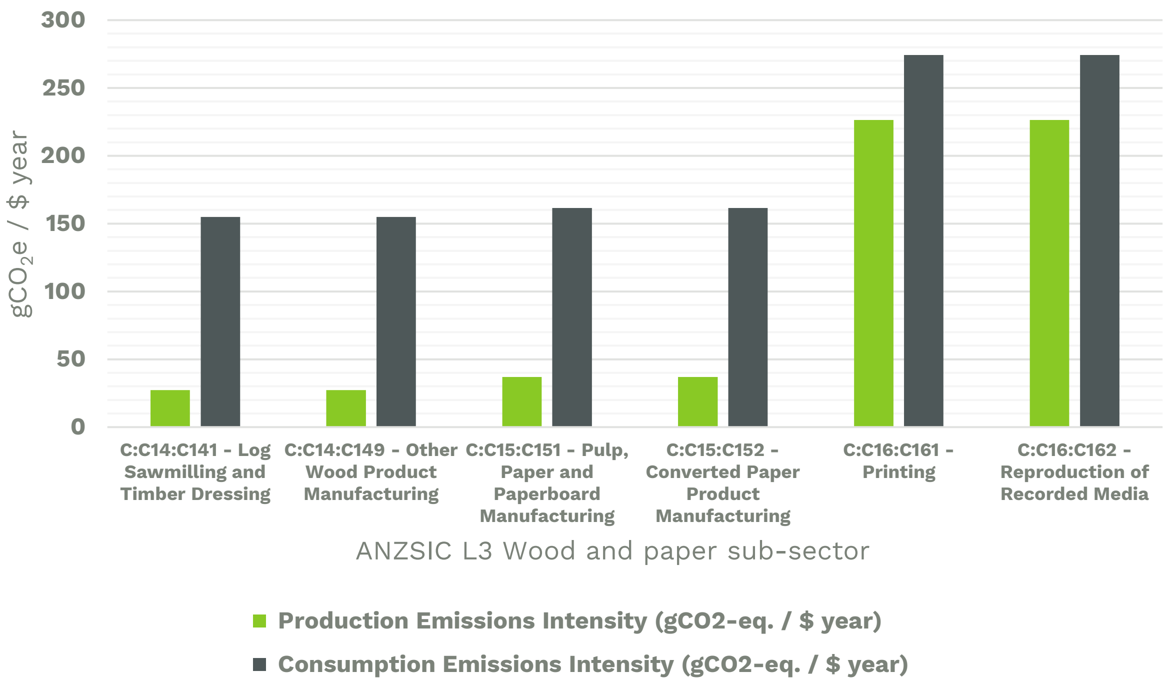

Figure 36 Production and consumption-based emissions intensities of the wood and paper manufacturing sector (gCO_2e / dollar-year), 2019 baseline

Production emissions intensities for wood and paper manufacturing are quite low compared to other sectors, with the gap between production and consumption emissions likely caused by supply chain emissions in these sub-sectors. This would include emissions associated with harvesting and transporting raw materials to manufacturing sites for processing. A high proportion of biogenic process heat is used in this sector, existing projects are underway to remove fossil fuel usage from the industry and there is low-value-add from forestry and wood product exports. We therefore suggest that ways to reduce these emissions intensities could be to increase the value-add from exports, reduce emissions from the forestry and logistics supply chains, and to focus on the reuse of existing or waste materials where possible. We note a focus on emissions intensities means some disconnection from total emissions footprints and overall reduction in absolute terms needs to be considered.

The emissions intensity of printing (which is modelled the same as reproduction of recorded media due to limitations in data aggregation), is comparatively very high. Considering the very high intensity allocated to reproduction of recorded media, and the negligible overall emissions figure, we deem these two sub-sectors as not a major priority for emissions reduction or circular economy opportunities.

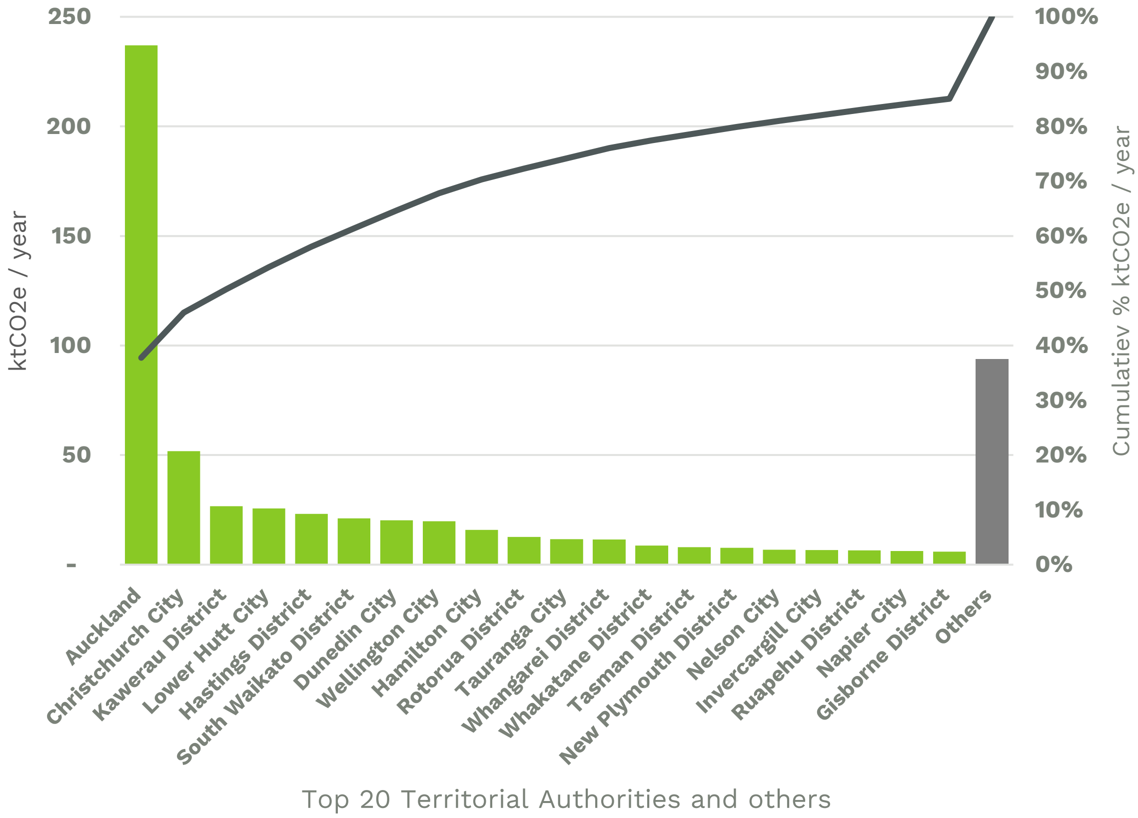

Figure 37 Annual production-based emissions of the wood and paper manufacturing sector across NZ territorial authorities (ktCO₂e / year)

After Auckland, which is the largest contributor for each of the advanced manufacturing sectors, Christchurch, Kawerau and Lower Hutt follow to account for approximately 54% of the national total.

We recommend the final top-down data set at ANZSIC level 3 is used for detailed analysis in the future, as the aggregation to the seven headline advanced manufacturing sectors can skew results and reduce the ability to pick out specific outcomes and opportunities for emissions reduction and circular economy.

Overall, the wood and paper sector is highly varied and each sub-sector seems to have a range of different import and export relationships. This may be a sector with more opportunities for implementing circular economy strategies, considering the by-products and co-products of manufacturing are transferable. This could even include using waste or low-value wood as feedstock for torrefied fuels such as bio-charcoal to use as a coal replacement for process heat or in thermal-power plants. It is understood some NZ companies are already implementing these initiatives, and this sector may be in a place to set the example for other advanced manufacturing sectors.

7.2.2. Waste

Focusing on potential wood and paper manufacturing waste generation, the following associated streams are outlined in Table 6.

Table 6 Wood and paper waste characterisation by waste material composition, SWAP categories

	Wood and paper	Identified source examples
Organics	✓	Slash, leaves
Cardboard and paper	✓	Offcuts, packaging
Timber	✓	Offcuts, packaging
Rubble/concrete (incl cleanfill)	-	-
Potentially hazardous	✓	Pulp mill sludge, ink and de-inking sludge
Plastic	✓	Offcuts, packaging
Metals	-	-
Textiles	✓	Personal protective equipment
Nappies and sanitary	✓	Personal protective equipment
Glass	-	-
Rubber (incl tyres)	-	-

Through qualitative resource flow scan activities, we identified potential waste outputs associated with wood and paper sector. Organics, timber and paper related flows dominated, although we note sub-sectors 'sanitary paper products' and 'reproduction of recorded media do not necessarily involve forestry-related inputs, and that treatments, coatings and inks applied through the manufacturing processes related to printing and finishing. This means some of the waste flows would be likely be plastics or chemical related. Personal protective equipment related waste streams are also identified as being associated with food-related packaging and hygiene products. Bleaching processes were identified as a contamination challenge associated with wastewater treatment. Processes related waste may include ash, dregs, grits, lime mud and pulp mill sludge, sawdust, offcuts, ink and de-inking related sludge, cleaning solvents and glues, all of which result in potentially hazardous waste outputs. We also understand several manufacturing facilities have private monofills to dispose of manufacturing waste, although details are commercially sensitive.

7.3. Bottom-up assessment

7.3.1. Qualitative resource flows

Part of the resource and waste mapping for the wood and paper sector included the development of material flow diagrams. These identify the key product, input resources, output co-products, by-products and waste products. It also identified opportunities for circular resource flows across ANZSIC level 3 and 4. Sub-sector material flow diagrams completed to date include:

- A combination of C141 Log sawmilling + timber dressing and C1510 pulp + paper (Figure 38)
- C1611 Printed + recycled cardstock (Figure 39)

These flow diagrams are shown on the following pages. Overall, this exercise has identified some key findings and opportunities.

- Kraft pulp mills conduct processes where chemicals and process heat are recovered and reused. Heat generated from the combustion of black liquor papermaking residues is used to generate stream for heating and powering the mill (Atkins, Options to Reduce New Zealand's Process Heat Emissions, 2019)
- Processing emissions can be reduced through thermal energy optimisation and process integration methods of process heat recovery. Pinch analysis to assist with this has been applied by the chemicals and refining, pulp and paper, and food and beverage sectors, but not widely (Atkins, Options to Reduce New Zealand's Process Heat Emissions, 2019)
- Continuous drying kilns operate in a counter-flow fashion in which heat is transferred or recovered. Supplied from Porirua, these kilns are an efficient improvement to drying sawn lumber process (Atkins, Options to Reduce New Zealand's Process Heat Emissions, 2019)
- Wood chip, a by-product of timber products, is used to produce MDF (Nelson Pine Industries Ltd, 2024)
- Partnerships between public sector and private industries is supporting innovation e.g. Ministry of Primary Industries, Te Uru Rākau NZ Forest Service and Oji Fibre Solutions investigating potential bio-hub at Kenleigh Mill (Te Uru Rakau NZ Forestry Service, 2023; Tomas, 2022); and MRINZ, Hikurangi Bioactives and TRG Natural Pharmaceuticals clinically trialing kānuka oil pharmaceuticals (Perry, 2022)
- End-of-life treated timber and timber construction waste is being converted and treated by Green Gorilla into clean biofuel used by Golden Bay Cement to replace coal (Green Gorilla, 2024)
- Waste untreated timber wooden pallets are examined for resale by companies like Green Gorilla or Goodwood or recycled into landscaping products and animal bedding for the dairy cow and goat industries (Green Gorilla, 2024; Goodwood Waste Solutions, 2024)
- The are examples at different scales of waste products from timber products being repurposed as bioenergy, e.g. residues burned in high efficiency furnaces to generate energy for drying and heating processing (Nelson Pine Industries Ltd, 2024; Azwood, 2023); slash could used to produce transport biofuels or

coal-replacing wood fuel (CarbonNews, 2023; Te Uru Rakau NZ Forestry Service, 2023); and sawdust as high energy pellet fuel (Azwood, 2023)

- There are price and processing disincentives for use of slash as biomass, e.g. cost of slash removal; lack of local slash processors; high-level of refining required; and safety issues of storing liquid fuels (Rennie, 2023; CarbonNews, 2023)
- Converting slash into solid pelletised biofuel is being investigated at a pilot scale. Slash and residue removal will reduce risks of forest fires, contaminated waterways, and land erosion (Rennie, 2023)
- Residue from whole log processing can be utilised for landscaping and livestock bedding (Azwood, 2023)
- Marlborough-based CarbonScape is investigating the opportunity for green-coke, a by-product of timber products that is microwave processed into refined carbon, to be used in steelmaking and in battery production (CarbonScape, n.d.; Hoyle, 2023). NZ Steel supported their venture for the first green coke production facility (Farrow, 2014)
- Lignin, a small percentage by-product of pulp and paper, is used in conjunction with wood-waste fuels to provide Kinleith Mill (which produces cellulose products for tissue and paper) with its 80% renewable energy (Oji Fibre Solutions, 2022). Lignin can also be used for resins and adhesives; foam manufacturing (Blue & Green, 2021) and pavement binding bitumen replacement (WSP, 2022)
- There is a growing market for non-timber forest products (MPI, 2023, wh. 5) that could support Māori business, e.g. oils such as kanuka used as pharmaceuticals (Perry, 2022); and bark-extract (Helleur, 2020)
- Reconstituted timber from the wine industry in the Marlborough and Hawke's Bay regions is being recycled into new fencing products for use on farms (Repost, 2022)
- Sawdust, a by-product of the milling industry, can be utilised by the food and beverage industry, e.g. applying as animal bedding, or on livestock paddocks to reduce nitrogen leaching and to improve soil health in vineyards and orchards (Azwood, 2023)
- Sawdust as a salt-alternative to great road grip in winter (Azwood, 2023)

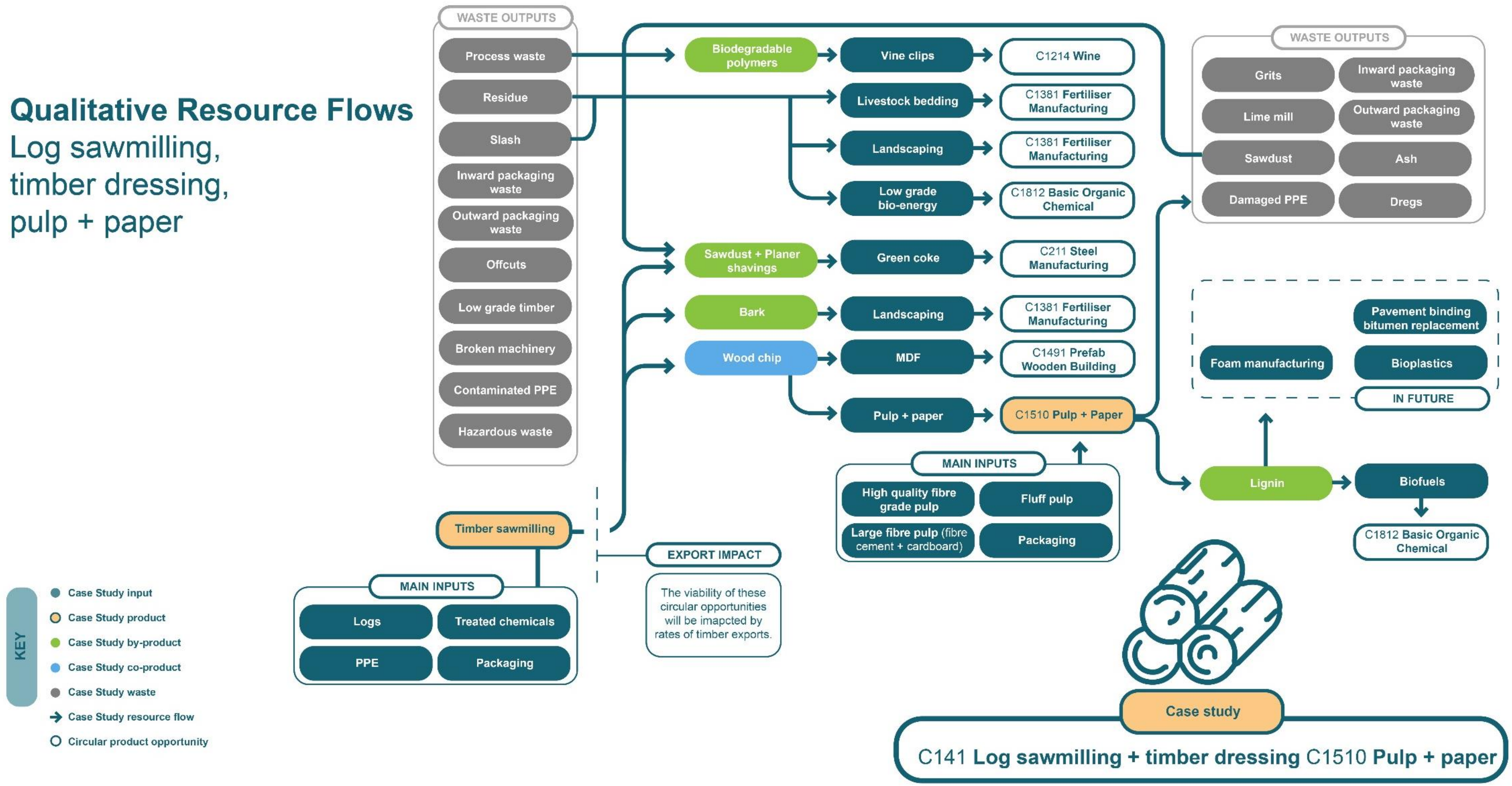

Figure 38 Resource flow map for log sawmilling and timber dressing (C141) and pulp and paper (C1510)

Qualitative Resource Flows

C1611 Printed + recycled cardstock

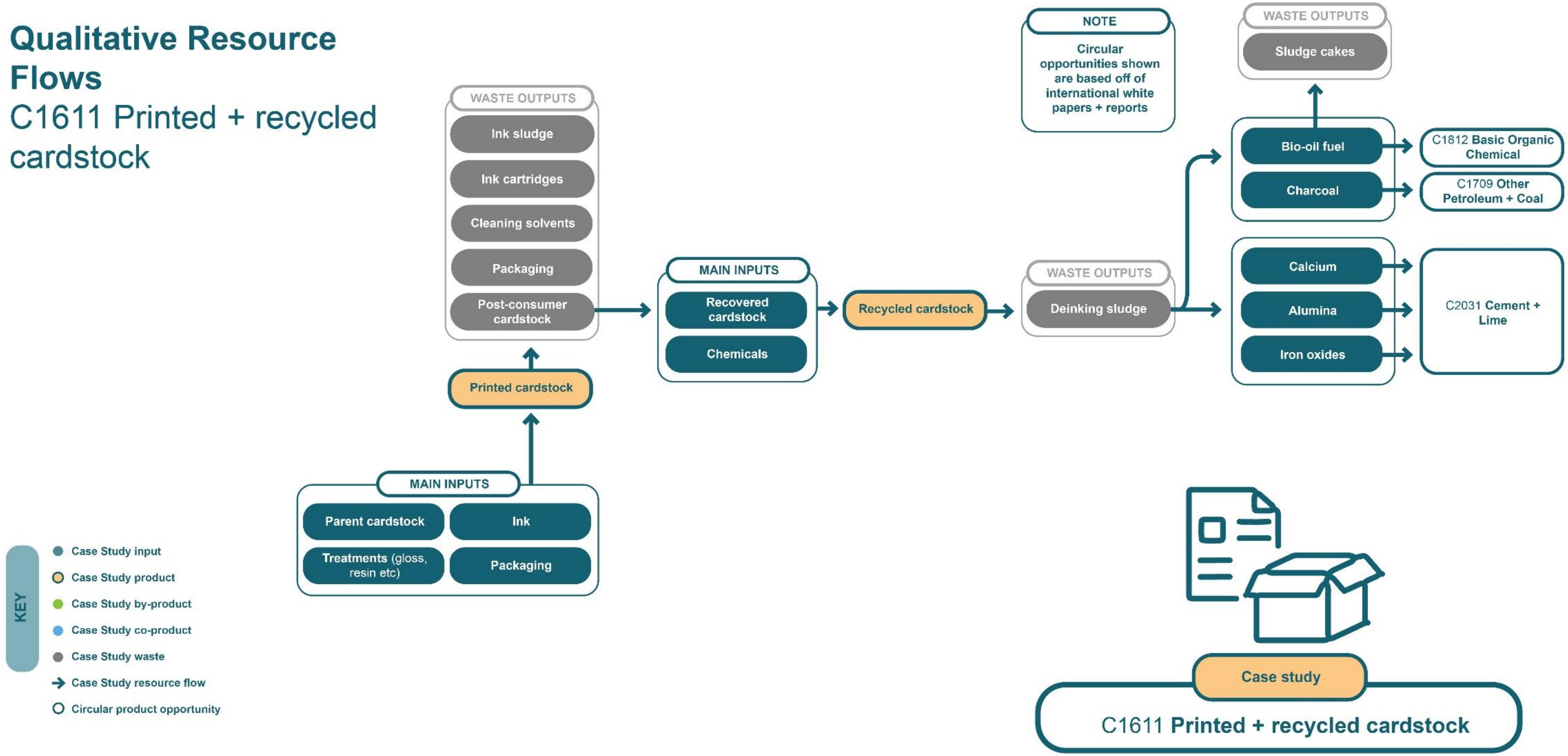

Figure 39 Resource flow map for printed and recycled cardstock (C1611)

7.3.2. Key material flows

Volume of the wood and paper in NZ, 2019
Sources: MPI, NZFAO, FAO, University of Waikato, MBIE
Units in m3 of solid wood per annum

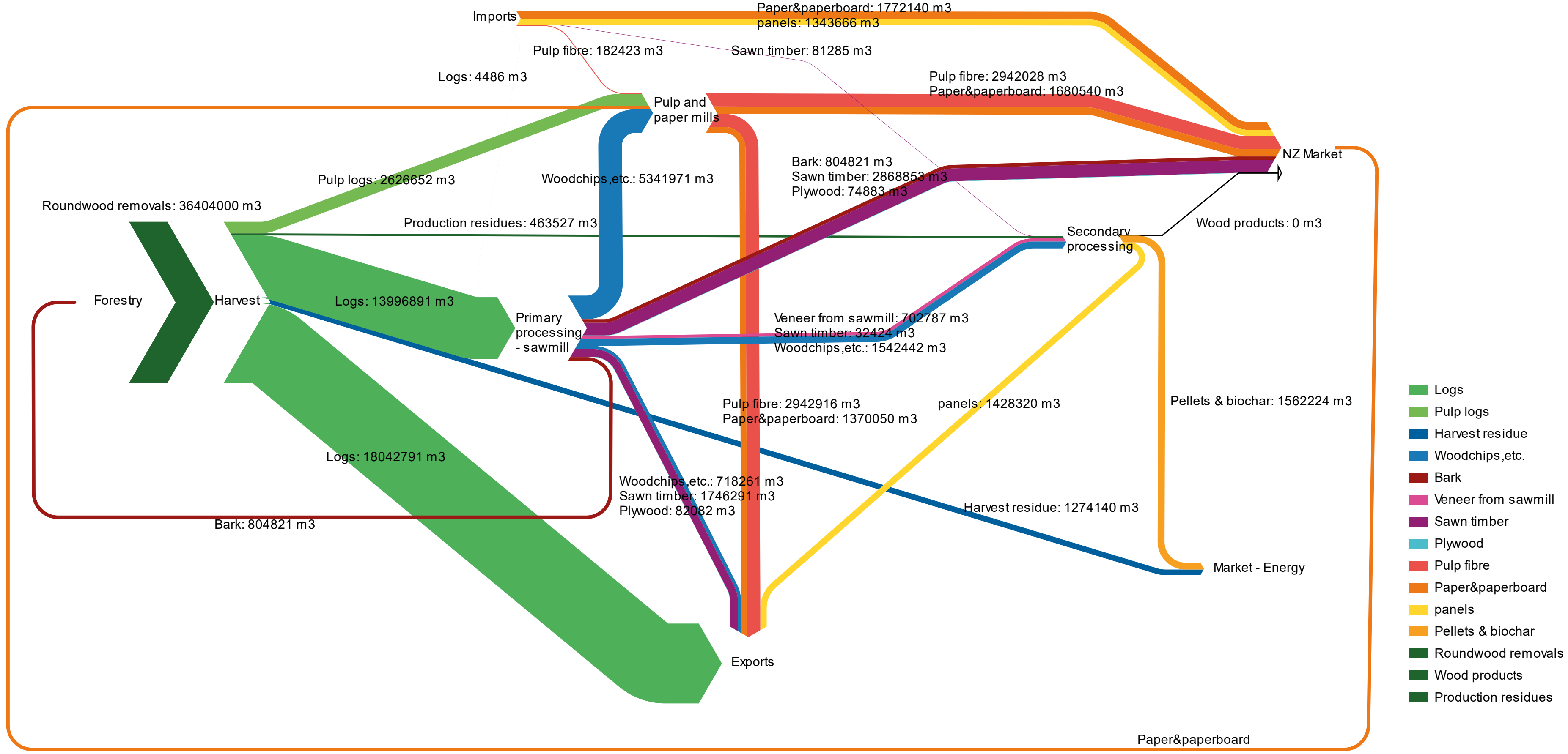

Figure 40 Wood and paper flows in New Zealand (2019)

7.3.3. Hotspots identified

The Sankey diagram for the wood and paper sector in New Zealand in 2019 details the volumes of different materials and products within the industry, measured in cubic meters of solid wood per annum. This diagram provides a snapshot of the industry's volume and material flows in terms of resource use and waste generation.

The key observations from the diagram were:

1. **Forestry and harvest volumes:** A significant volume of roundwood (36,404,000 m^3) is removed from forests. Of this, 13,996,891 m^3 of logs are directed to primary processing, such as sawmills and 18,042,791 m^3 are exported.
2. **Primary processing:** Primary processing generates a variety of products, including sawn timber (4,647,568 m^3), wood veneer (702,787 m^3) and plywood (156,965 m^3). By-products such as woodchips (7,602,674 m^3) and bark (804,821 m^3) are also produced, which can be used in further processing or as biomass for energy.
3. **Exports:** In addition to the 18,042,791 m^3 of exported logs, a substantial portion of processed products are also exported. These include pulp fibre (2,942,916 m^3), sawn timber (1,746,291 m^3), paper and paperboard (1,370,050 m^3), woodchips (718,261 m^3), and plywood (82,082 m^3).
4. **Pulp and paper mills:** 2,626,652 m^3 of pulp logs and 5,341,971 m^3 of woodchips are processed into pulp fibre (5,884,944 m^3), roughly half of which is exported as pulp fibre and half used by the NZ Market. Of the remaining 3,050,590 m^3 that is converted to paper and paperboard, 1,680,540 m^3 is consumed by the NZ market and 1,370,050 m^3 is exported.
5. **Secondary processing:** 1,542,442 m^3 of woodchips, 702,787 m^3 of veneer, and 32,424 m^3 of sawn timber from primary processing flow into secondary processing, alongside 463,527 m^3 of production residues from harvesting. This results in 1,428,320 m^3 of panels for export, 1,562,224 m^3 of pellets, biochar and a variety of other wood products for the New Zealand market that we could not quantify.
6. **Energy market:** There is a considerable flow of material towards the energy market, represented by pellets and biochar (1,562,224 m^3) and harvest residue (1,274,140 m^3), indicating that roughly 7.8% of the roundwood removals in New Zealand is utilised for bioenergy purposes.
7. **Waste and residue management:** Production residues account for 463,527 m^3, while harvest residue amounts to 1,274,140 m^3, suggesting that waste management is a notable aspect of the sector's operations. Another 804,821 m^3 of bark is fed back into the forestry sector from primary processing, presumably as mulch or soil conditioner. Except for paper and paperboard, the end-of-life stage for wood products in the New Zealand market and for exported products is not represented in the diagram. Many of these materials will remain in stocks within the economy for some time before being reintroduced as a waste flow. Paper and paperboard recycling is represented graphically, despite a lack of data on the specific volumes.
8. **Imports versus domestic production:** The diagram shows that there is a significant level of domestic production but that imported paper and paperboard (1,772,140 m^3) and timber panels (1,343,666 m^3) still play a role in meeting the market demand in New Zealand. Additionally, domestic pulp and paper mills use 182,423 m^3 of imported pulp fibre and 81,285 m^3 of imported sawn timber is used by secondary processing in New Zealand.

7.4. Location

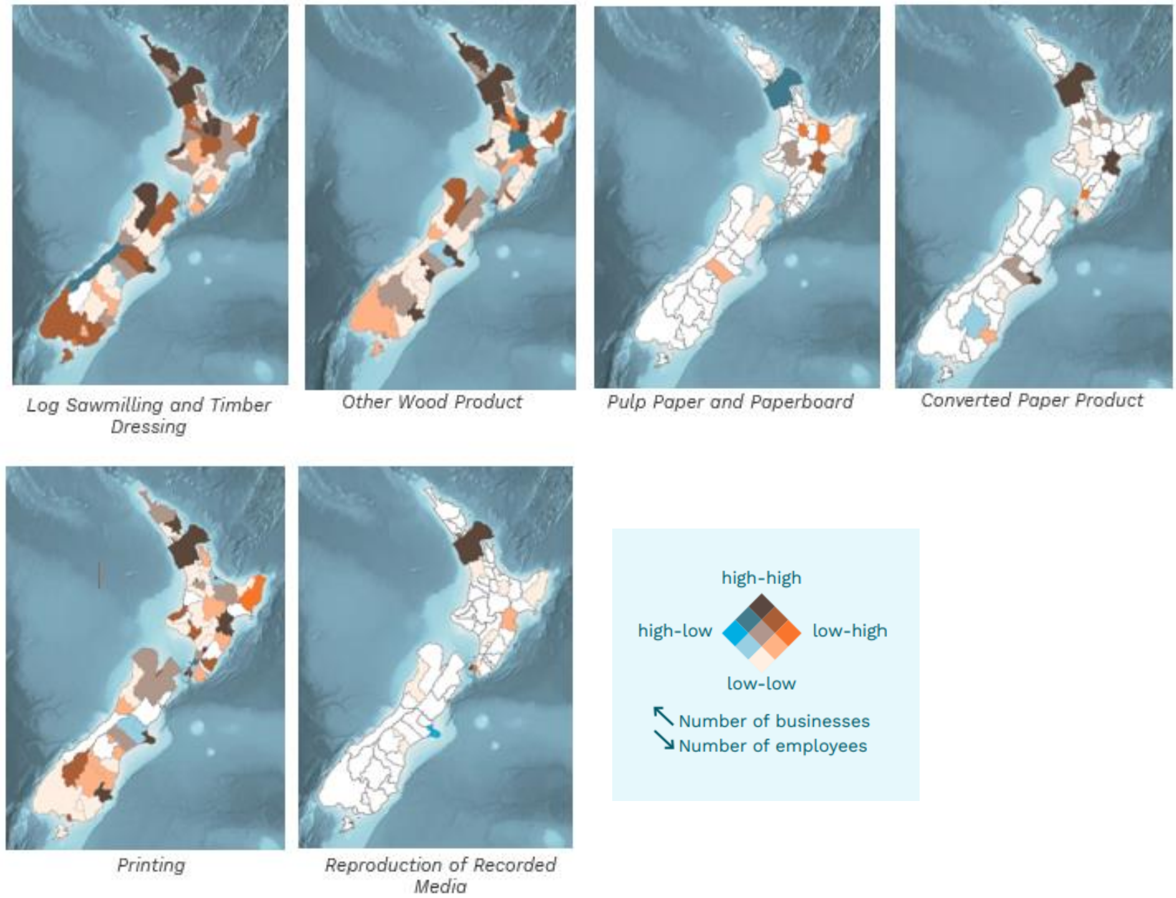

Figure 41 Manufacturing activity location – Wood and paper ANZSIC Level 3 by territories, 2019

Wood product manufacturing activity operates predominantly in Auckland and Christchurch City, followed by Rotorua District, Tauranga City, Whangarei District and Far North District. The Bay of Plenty, Far North, and Otago regions are near forestry plantations and rail lines, enabling transport to major cities.

Pulp, paper, and converted paper product manufacturing activity mostly occupies Auckland, Christchurch City, followed by Hastings District, and Kawerau District. Often the by products from wood product manufacturing are used in pulp, paper and converted paper product manufacturing. The largest pulp and paper mill is the Tasman Mill located near the Kāingaroa forest near Kawerau. Similarly to wood product manufacturing, the manufacturing activities are located near forestry. Although Hastings is a major player in pulp, paper and converted paper product manufacturing, it is due to the strong forestry industry in the Hawkes Bay.

Printing is strongly anchored in Auckland, Christchurch City, Lower Hutt City and Wellington City.

7.5. Data gaps

As with other sub-sectors, a range of data gaps were identified for the wood and paper sub-sector. Some of these gaps related to flows that were anticipated but not identified, such as Kawerau, where we expected to identify more paper manufacturing.

We identified a lack of data concerning the consumption of water and the handling of by-products from the sub-sector, such as waste and post-logging residues. A number of manufacturing facilities were known to have private monofill waste sites, but there was a lack of data on these. We also noted a lack of knowledge over the end-of-life fate of materials, particularly those being exported as well as some of the internal flows within the New Zealand economy.

We were unable to accurately describe the emission intensity of some flows, including printing.

Generally, a need was perceived by stakeholders to leverage data more effectively towards achieving sustainability goals and the need for digital tools and platforms for data management were seen as crucial to the future success of achieving these goals.

7.6. Stakeholder perspectives

Participants in the workshop and interviewees highlighted significant gaps and challenges in capturing accurate data within the wood and paper sector, especially regarding waste, by-products, emissions and water use. The complexity of accurately accounting for all aspects of the sector, such as post-logging residues and waste treatment, was underscored as an area needing improvement.

The efficiency of domestic production versus international alternatives and the potential for increasing domestic consumption of timber products were areas of interest. Challenges in accurately mapping the flow of materials and waste within the sector were noted, alongside the potential for future investments to lead to circular opportunities.

A lack of detailed data on water usage, wastewater management and the environmental impacts of forestry waste was identified. Suggestions for obtaining this missing data included engaging with industry groups, further leveraging trade and customs data, and exploring recent studies on carbon emissions and water flows through forests.

Opportunities for a net-zero circular sector include greater domestic consumption of timber products, development of engineered wood products and bioenergy from waste. The industry's needs in transitioning to a circular economy involved better data collection and sharing mechanisms, the development of digital tools for data management and infrastructure to support biotech waste reuse product development.

Sector-specific practices and challenges:

- **Waste and recycling management:** Innovations in recycling and bioeconomy efforts, particularly in developing bioenergy and bio-refining capabilities, highlight the sector's focus on sustainability. Challenges include managing low-grade materials and finding markets for waste products.
- **Emissions management:** The sector's discussions around emissions primarily focus on material recovery and potential bioenergy rather than direct emissions management. Strategies for leveraging industry data to enhance sustainability goals were less directly addressed.
- **Manufacturing processes and environmental Impacts:** Detailed insights into manufacturing processes from raw material sourcing to end-of-life disposal or recycling emphasise the importance of sustainable practices, including the reuse of sawmill byproducts and exploration of non-timber forest products.
- **Collaboration and innovation for sustainability:** The importance of cross-sector collaboration and the adoption of innovative technologies to support the circular economy were highlighted. Efforts to develop digital tools and platforms for data management and enhance traceability across the supply chain were seen as crucial for the sector's sustainability goals.

7.7. Sub-sector conclusions

The wood and paper sub-sector in New Zealand is heavily represented by wood processors in the central North Island, followed by Otago and Southland. Forestry and wood products contributed 8.9% of the national GDP in 2020 and are New Zealand's third largest export after dairy and meat. Raw logs dominate the sub-sector, but New Zealand also exports a wide range of processed wood products. In recent years, paper production has declined, corresponding with a decline in demand for newsprint. Auckland, Christchurch, Hastings and Rotorua accounted for approximately 70% of the national total.

Despite the substantial domestic production, our bottom-up analysis indicated a significant importation of paper, paperboard and timber panels, suggesting an ongoing import of wood and paper within imported products and packaging.

From our top-down assessment, the data suggested that most emissions may arise from forestry, with manufacturing contributing relatively little. However, this may be masked by the data set, which only included fossil fuels and did not consider the use of biomass. While biomass is often viewed as climate neutral, this nevertheless represents a gap in this assessment. In terms of emission intensity, printing and reproduction of recorded media stood out. However, it was believed that the increased intensities for this application were linked more to the manufacturing process than to the materials. The substantial use of rail for transporting timber was suggested.

Compared with other sectors, the emission intensities for wood and paper were relatively low, with greater consumption-based intensities linked to harvesting and transportation emissions.

From a waste perspective, a wide variety of waste streams were identified, primarily organic but also including inks, preservatives, plastics, adhesives and a wide variety of byproducts such as ash and sawdust.

Our bottom-up analysis identified the significant use of timber byproducts for energy through wood pellets and biochar. This included the substantial use of harvest residue and suggested that roughly 7.8% of roundwood removals in New Zealand were utilised for bioenergy purposes in 2019. Stakeholder engagement indicated a lack of data and a desire for improvements in tracking waste treatment and post-logging residues.

A lack of information on water usage, wastewater management and the environmental impacts of forestry were also communicated by stakeholders.

Waste management appears to represent a substantial aspect of the sector's operations, particularly handling harvest residue and bark. The end-of-life fate of New Zealand wood and paper products was unclear, with a substantial quantity being exported or ending up as stocks within the New Zealand-built environment. This means the overall sequestration of biogenic carbon over time is challenging to calculate.

The increased domestic use of wood and paper was highlighted as an opportunity to transition to a net-zero circular sector with the expanded use of engineered timber, timber products and bioenergy from waste.

8. Metal and metal products sub-sector

8.1. Sub-sector overview

Metals manufacturing is dominated by major players such as NZ Steel and NZ Aluminium Smelter (NZAS). Smaller producers in the non-ferrous market include boutique gold refining, Oceana Gold's gold and silver smelting, and Hayes Metals' copper-based alloy smelting, although these are all significantly smaller operations. Metal smelting is primarily conducted at Tiwai Point in Southland and at Glenbrook, with much smaller non-ferrous smelters in Otago, Waihi and Auckland for gold, silver, copper and brass alloys, respectively.

Although there are a small number of large suppliers, such as NZ Steel's Colorsteel and the Pacific Steel reinforcing plant, downstream product manufacturing is more distributed than metal production and generally less emissions-intensive. There are important links from these sub-sectors into other manufacturing sub-sectors, especially machinery and equipment, as well as downstream uses in the infrastructure, and building markets.

There is a difference in terminology used throughout the ANZSIC codes and elsewhere within the industry – primary metal production generally refers to the raw metal production, secondary metal production relates to products made of metal. Note that this is different to other language used in this sector specifically, where primary metal indicates virgin and secondary indicates recycled content.

Domestic developments to increase the recycling capacity in NZ are underway, notably the commissioning of a new Electric Arc Furnace (EAF) at NZ Steel in Glenbrook, although this is not projected to come online until 2027. At present, recycling is limited to smaller players including McKechnie, a producer of aluminium extrusion profiles, and Hayes, mentioned above. Despite growing international demand for aluminium, there is uncertainty in the long-term viability of the NZAS smelter at Tiwai Point, which exports almost all of its product. If the smelter closes, it will have a significant impact on the industry, lowering domestic carbon emissions, but having an uncertain impact on global emissions.

8.2. Top-down assessment

8.2.1. Greenhouse gas emissions

The top-down emissions account of the metals and metal products sector shows that the basic metals manufacturing sub-sectors have very high production emissions, with metal product manufacturing emissions being dominated by imports and the wider supply chain.

The differences between production and consumption-based emissions for the basic metal manufacturing sub-sectors (ferrous and non-ferrous) are smaller than those for metal product manufacturing. This shows that for raw metal production, most emissions come from onsite emissions such as energy usage, rather than the supply chain. Both the aluminium and the steel sectors are considered 'hard to abate' and emissions reducing activities are capital-intensive where they exist.

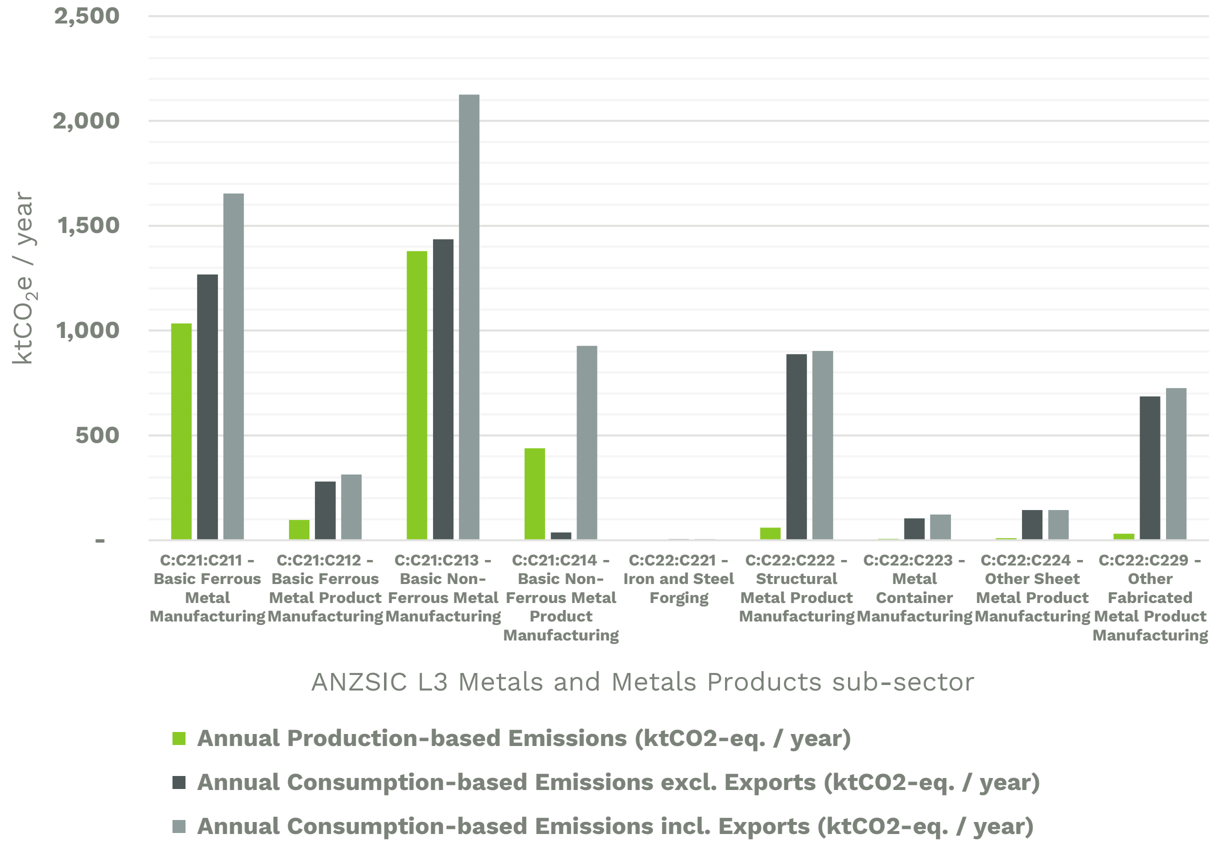

Figure 42 Annual production and consumption-based emissions from the metal and metal products manufacturing sector (ktCO₂e / year), 2019 baseline

Globally, emissions from primary aluminium production mainly come from the electricity used to reduce the refined alumina to aluminium metal, but the Tiwai Point smelter's electricity is exclusively sourced from the Manapōuri hydro scheme, effectively eliminating direct emissions from this energy source. Remaining impacts come from industrial processes and product use (IPPU) emissions where the carbon anodes used for production 'burn' and combine with oxygen in the electrolyte to produce CO_2, as well from the energy needed to produce and 'bake' these anodes. Around the world, pilot projects to replace these carbon anodes with inert alternatives exist, but this may not be an option for New Zealand industry, especially given that the short-term power purchase agreements used by NZAS make it challenging to justify long-term investments.

Reducing emissions from the primary steel industry has similar challenges to the aluminium industry, with international pilot facilities using green hydrogen, bio-coke or direct electrolysis to reduce iron ore to iron metal. All of these require capital-intensive plant upgrades and rely on either large quantities of renewable electricity, or torrefied biomass.

One of the key changes to the NZ manufacturing landscape since the data used for the top-down study was released in 2019 has been the announcement that NZ Steel is constructing an electric arc furnace (EAF) to restart onshore steel recycling. This will reduce local steel emissions by transitioning from primary to secondary production, boosting the local circular economy in this sector. This is a partial shift for the plant, which will still produce about half its product from coal-based primary steel when the project is commissioned in 2027, meaning there are still opportunities for further reductions.

Note that the domestic consumption numbers for primary metals have been estimated from external resources and the full data was not provided in the Stats NZ data set due to confidentiality issues. This may affect the accuracy of the production- and consumption-based emissions. Similarly, we see no data for iron and steel forging. A small amount of domestic production ($25.47 million) is included in Stats NZ data, but no import or export numbers are provided in the System of Harmonised Trade. This could be a combination of confidentiality, the products being entirely served by domestic consumption or products being assigned to other ANZSIC categories in the data.

We note that basic non-ferrous metal products have a much larger production-based emissions footprint than for consumption, except when considering exports. This indicates that much of this sub-sector's production is exported for international consumption.

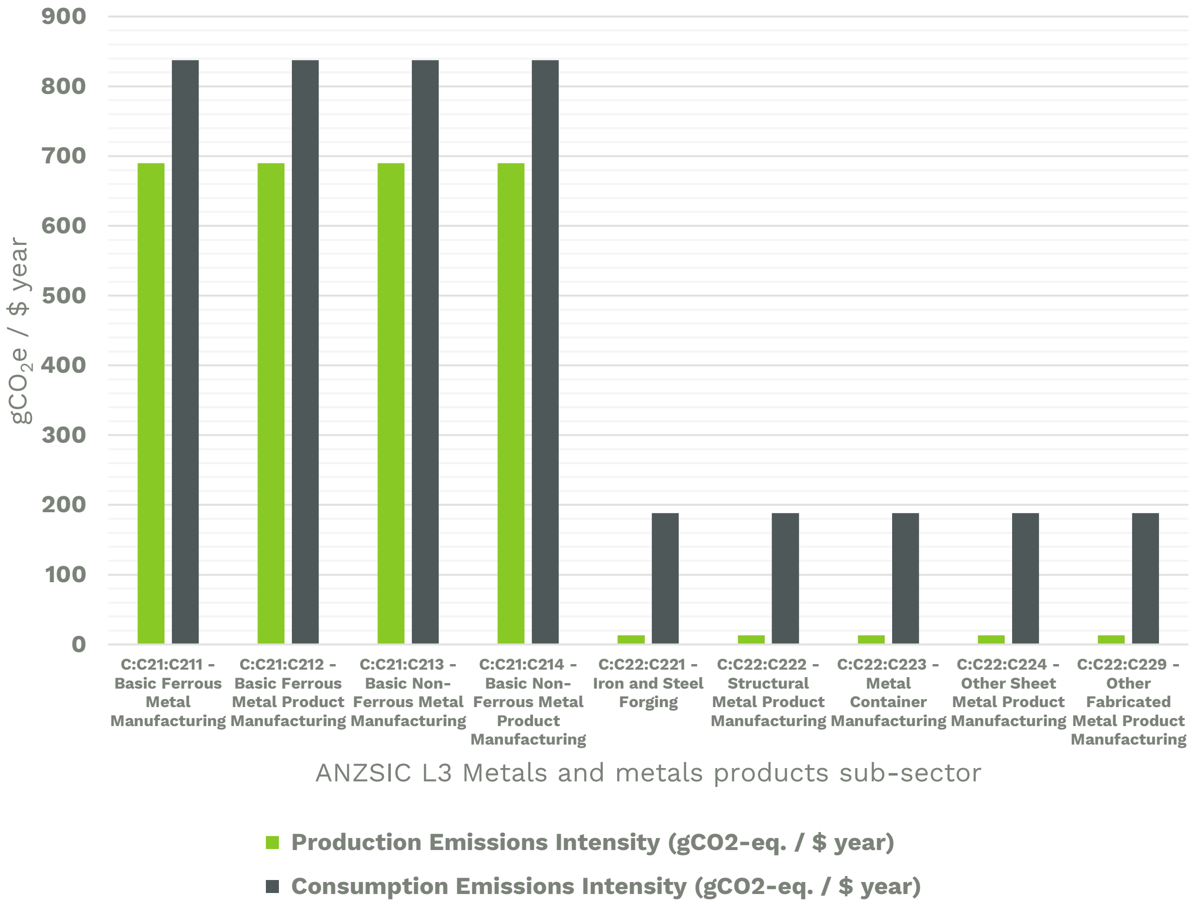

Figure 43 Production and consumption-based emissions intensity for the metals and metal products manufacturing sector (gCO_2e / year), 2019 baseline

The high consumption-based emissions for the metal products sub-sectors (structural metal, containers, sheet metal, and other fabricated products) is likely a combination of importing complete manufactured goods, and the very high consumption intensity compared to production. This makes sense as the supply chain for these products would include the primary metals production-based emissions which are considerable. We again see the effect of one-to-many mappings in the background data, with all products being allocated a single emissions intensity. The effect of this assumption is detailed in Sensitivity analysis, Section 13.

The emissions intensities for primary metals and products are the second highest of all the manufacturing sector in NZ, second only to petroleum and chemicals refining.

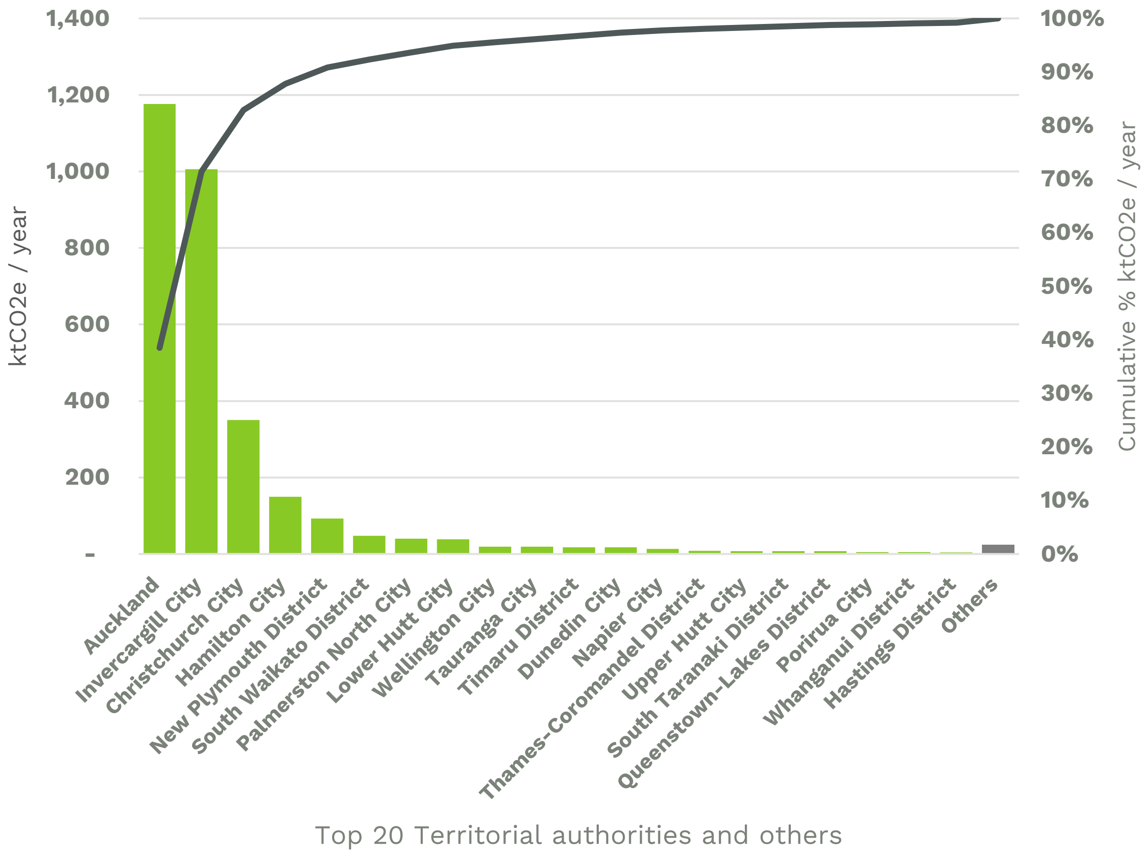

Figure 44 Annual production-based emissions from the metals and metal products manufacturing sector across NZ territorial authorities (ktCO₂e / year), 2019 baseline

The regional breakdown of emissions once again shows Auckland as the key player, with more employed in metals manufacturing than other regions and the Glenbrook steel mill being a significant employer and emitter. Similarly, Palmerston North and Hamilton are the next largest with significant metal product production facilities. Interestingly, we would expect a larger contribution from Invercargill due to the location of the Tiwai Point aluminium smelter in the area. This region has lower production emissions than Lower Hutt for example, which has no large primary metal manufacturing but a large amount of metal product manufacturers in industrial areas like Petone, Seaview and Gracefield.

Overall, we see the metals and metal products can be considered in two camps, primary metal manufacturing with a large production-based footprint (and very regional) and secondary metal products (smaller production footprint, but large supply chain emissions) which is scattered throughout the country. The highly regional aspect of primary metals, and the fact that most of the overall consumption-based footprint is from the upfront manufacturing/production and associated energy use, means this would be a suitable sector to focus on for decarbonisation. While metals manufacturing is a smaller industry than other sectors by value, the high emissions intensity of the sector means the total emissions footprint is still comparable with those larger industries (e.g. metals manufacturing production emissions being 3,056 ktCO_2e, and worth $2.82 billion, and food and beverage production emissions being 3,903 ktCO_2e, but being worth $7.46 billion).

8.2.2. Waste

Focusing on potential metals and metals products manufacturing waste generation, the following associated streams are outlined in Table 7.

Table 7 Metal and metal products waste characterisation by waste material composition, SWAP categories

	Metal and metal products	Identified source examples
Organics	-	-
Cardboard and paper	✓	Packaging
Timber	✓	Packaging
Rubble/Concrete (incl. cleanfill)	-	-
Potentially hazardous	✓	Sludge waste, machinery oils and lubricants, casting material, oxidised product, acids from pickling/hydrochloric acid
Plastic	✓	Packaging
Metals	✓	Offcuts and defective product, excess alloys, n.b. internal recycling practice observed
Textiles	✓	Personal protective equipment
Nappies and sanitary	✓	Personal protective equipment
Glass	-	-
Rubber (incl. tyres)	-	-

Through qualitative resource flow scan activities, we identified potential waste outputs associated with production. Metal manufacturing is diverse, with dominant players focused on one metal type such as steel or aluminium. Potentially hazardous waste streams require further investigation to better understand specific challenges related to processing of different product. We note some manufacturing facilities also have monofill disposal sites that manage a range of waste outputs within consenting requirements. We also observed recycling internally was common practice. Although this is managed effectively through existing circular practices in the sector some metal waste streams can be expected. Slag produced is considered a by-product as this is re-processed and used.

8.3. Bottom-up assessment

8.3.1. Qualitative resource flows

Part of the resource and waste mapping for the metals and metal products sector included the development of material flow diagrams at ANZSIC level 4. These identify the key product, input resources, and output co-products, by-products, and waste products. It also identified opportunities for circular resource flows across ANZSIC level 3 and 4. Sub-sector material flow diagrams completed to date include:

- C2110 Steel and C2121 Iron + Steel Casting (Figure 45)

These flow diagrams are shown on the following pages. Overall, this exercise has identified some key findings and opportunities.

- Slag from iron and steel making can be repurposed by other manufacturing and chemical and refining sub-sectors for construction purposes e.g. supplementary cementitious materials (SCMs) for cement (ConcreteNZ, 2024); as filtering media for wastewater treatment, drainage material as EcoFlow, roadsurfacing and soil-conditioning (NZ Steel, 2024)
- Chemical and refining is a common end-user of by-products of iron smelting and steel manufacturing, e.g. slag for wastewater treatment (Sustainable Steel Council, 2020, wh. 3); melter aggregate for high skid resistance on roads (Sustainable Steel Council, 2020, wh. 3); titanium dioxide as pigment for paints and dyes (Coyle, 2022); iron oxide for cosmetic colouring agents or magnetic media (NZ Steel, 2024); laboratory research for iron as ferrous sulphate for use in baby formula, and supplements (Richardson, 2024)
- NZ Steel are using external scrap for their electric arc furnace, replacing two rotary kilns and one of the two malters (NZ Steel, 2023)
- There are numerous opportunities to reuse resources internally in ferrous and non-ferrous manufacturing and casting e.g. process gases can be reused for heating and electricity (NZ Steel, 2024); hydrochloric can be regenerated and reused in pickling baths (NZ Steel, 2024); casting sand can be reclaimed for reuse on site (Judd, 1997); metal dust from production can be reused or resold (Sustainable Steel Council, 2024); damaged product can be reprocessed (NZ Steel, 2024); and reduced primary concentrate and char can be reproduced into making iron (NZ Steel, 2024)
- Opportunity identified by Tiwai to produce green hydrogen to replace coking coal in the steel making process (Metals NZ, 2022)
- Vanadium has been extracted from steel slag at pilot scale in New Zealand and used to double steel alloy's strength, and for vanadium redox flow batteries, a renewable energy source (Coyle, 2022)

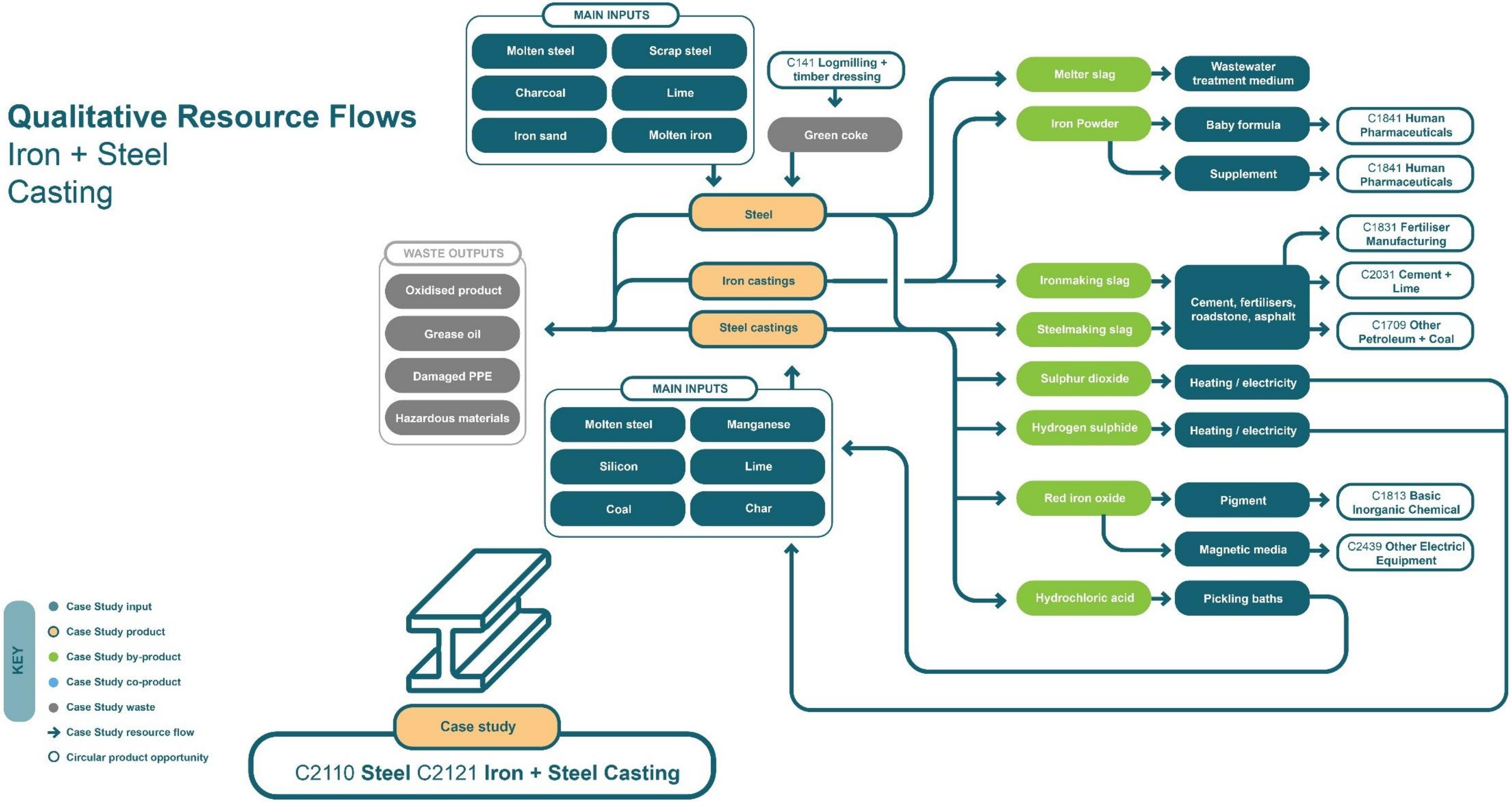

Figure 45 Resource flow map for Iron and Steel Casting (C2121)

8.3.2. Key material flows

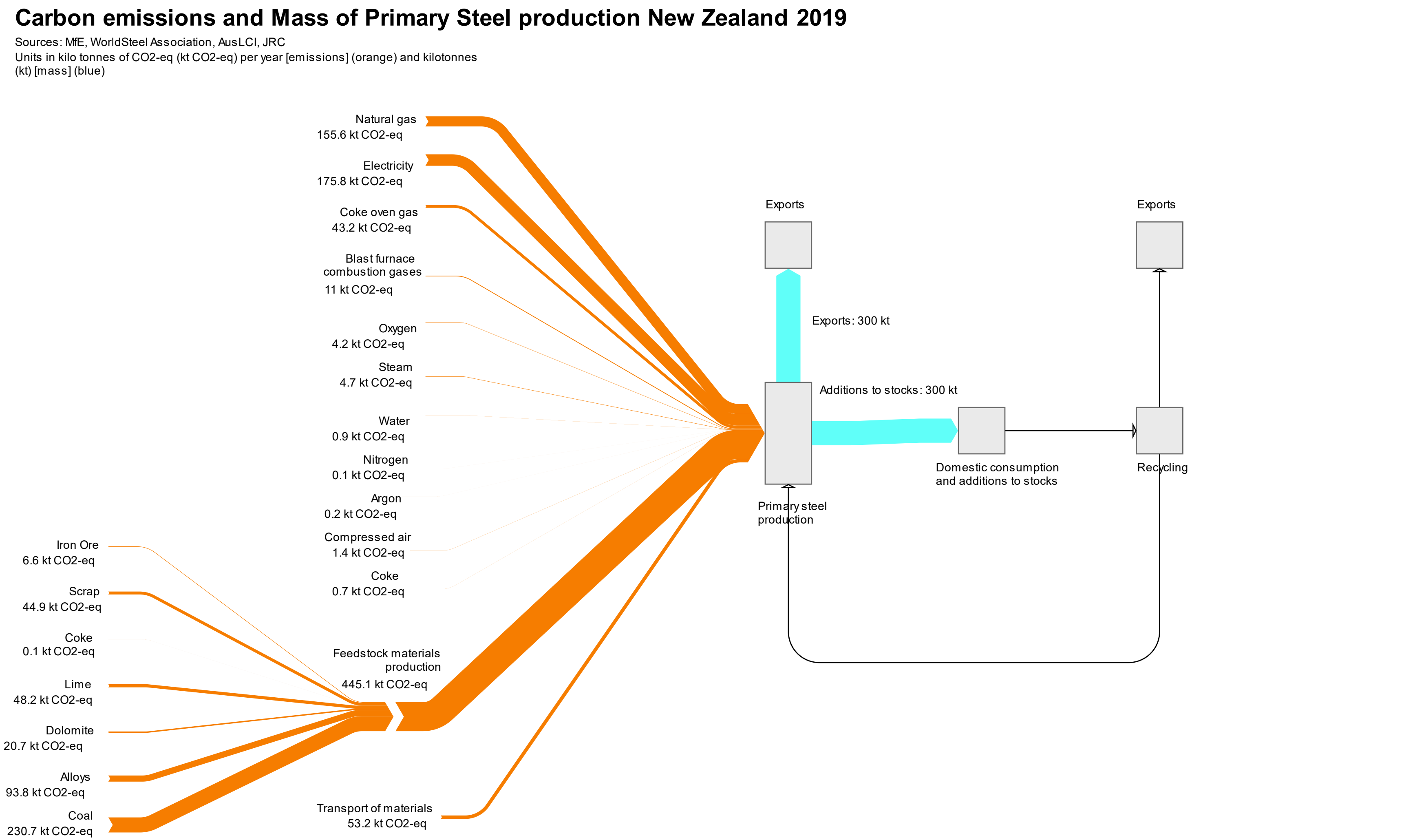

Figure 46 New Zealand Steel sector emissions and material flows (2019)

8.3.3. Hotspots identified

Figure 46 outlines the carbon emissions and material flows associated with primary steel production in New Zealand for 2019. The key points identified were:

1. **Carbon Emissions from Energy:** The diagram lists several inputs to steel production and their associated carbon emissions totalling 616.3 kt CO_2e. The largest contributors to emissions include coal (230.7 kt CO_2e), electricity (175.8 kt CO_2e), and natural gas (155.6 kt CO_2e). Coke oven gas and blast furnace combustion gases accounted for an additional 43.2 kt CO_2e and 11 kt CO_2e, respectively.
2. **Feedstock Material production:** Over 214.2 kt CO_2e of emissions were associated with the production of feedstock materials, including alloys (93.8 kt CO_2e), dolomite (20.7 kt CO_2e), lime (48.2 kt CO_2e), scrap (44.9 kt CO_2e), iron ore (6.6 kt CO_2e).
3. **Transport Emissions:** Transporting these materials also contributes to the carbon footprint, with emissions totalling 53.2 kt CO_2e.
4. **Exports:** New Zealand exported 300 kt of primary steel in 2019, demonstrating the capability and scale of steel production for external markets.
5. **Domestic Consumption and Stock Additions:** There is an equal amount for additions to stocks and domestic consumption of primary steel production, also amounting to 300 kt. This indicates a balance between domestic consumption and export.
6. **Recycling:** The diagram indicates the likelihood that some portion of used steel goes into recycling, but we could not identify the volume.
7. **Emissions from other Gases:** Various other gases used in the production process, such as oxygen, nitrogen, argon, and compressed air, all accounted for smaller portions of the environmental footprint.

8.4. Location

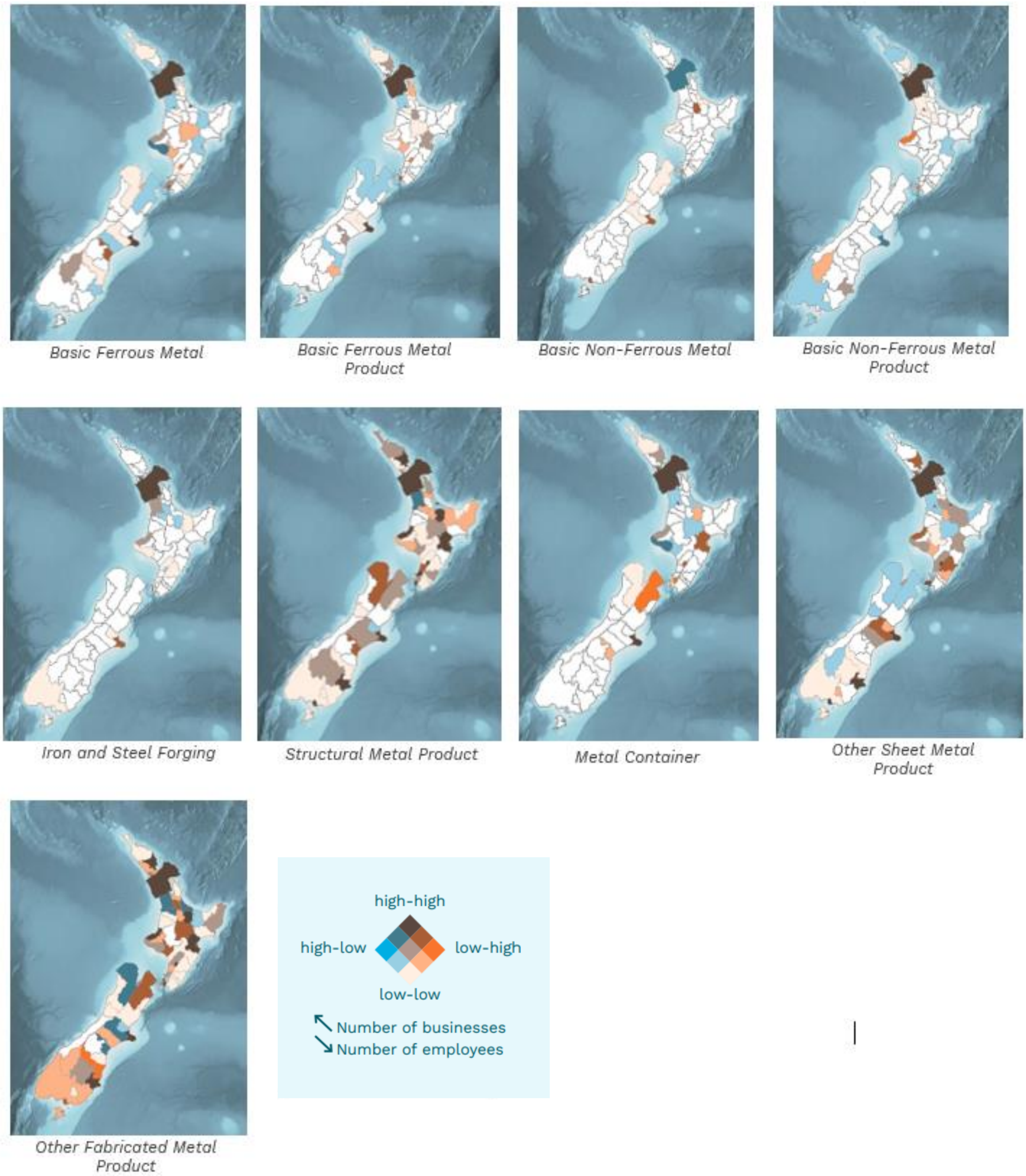

Figure 47 Manufacturing activity location –metal and metal product ANZSIC Level 3 by territories, 2019

Primary metal and metal product manufacturing activity is mostly found in Auckland, Christchurch City and Hamilton City. Being situated in major cities enables businesses in this sub-sector to have access to a strong, reliable energy source which is essential for their operations.

Fabricated metal product manufacturing activity is dominated in Auckland, and Christchurch followed by Hamilton, Tauranga City, and New Plymouth District. Similarly, to primary metal and metal product manufacturing, the locations are in major cities.

Auckland is a prime location for Fabricated metal product manufacturing due to the large construction and infrastructure sector in the city.

8.5. Data gaps

Given the sector emissions are dominated by larger companies, especially for metal production, smaller players can become lost in the noise. Industries such as copper-based alloy smelting and refining, and gold/silver smelting are not able to be parsed in the top-down data, with bottom-up data not available for analysis.

The issues when mapping top-down data across the ANZSIC and NZSIOC formats amplify this challenge, assigning the same emissions intensity factors across the sub-sectors. As part of the sensitivity analysis conducted for the top-down assessment, the metals sector was chosen to investigate a potential improvement strategy, and this is explored further in Sensitivity analysis, section 13.

Bottom-up data was only available for the ferrous metal production sub-sector. Therefore the rest of the sector (including non-ferrous metal production and all downstream product manufacturing and fabrication activities) do not have bottom-up data sets. This also means there is no data to support the integration of the metal product manufacturing sub-sector with linked sectors such as machinery and equipment manufacturing. Work conducted as part of Project 1, MBIE Circular Economy Research Programme suggested that these are important, although data was not available to map imported versus domestically sourced product inputs in detail.

8.6. Stakeholder perspectives

Workshop participants and industry representatives highlighted discrepancies in the emissions data, particularly the aggregation of aluminium and steel emissions, which posed challenges to accurately assessing the sector's emissions profile. There was a consensus on the need for more current and granular data, especially concerning waste stream data, to represent the sector's environmental impact accurately.

Participants found the data on primary steel manufacture emissions interesting, especially where it shed light on the significant roles of coal and natural gas. Participants were keen to understand domestic versus offshore recycling dynamics and the potential for future investments in enhancing domestic recycling capabilities.

A notable gap identified was the lack of detailed data on recycling processes and the destinations of recycled metals, both domestically and internationally. Suggestions for bridging these gaps included leveraging up-to-date industry surveys and customs data and engaging with entities like Toitū Envirocare and the Sustainable Business Network.

The discussions revealed opportunities for enhancing metal circularity through improved sorting, design for recyclability, and business models promoting metal reuse and recycling. The industry's needs were articulated as more explicit government policies to encourage circular practices, address logistical challenges, and foster collaborative models to enhance sector-wide circularity.

Sector-specific practices and challenges:

- **Waste and recycling management:** Representatives highlighted significant recycling efforts within the sector, particularly for steel, emphasising the circular economy model where metals are recycled and repurposed without losing integrity. Collaborations with prominent recyclers underscore the industry's commitment to sustainable practices.
- **Emissions management:** While directly addressing scope 1, 2, and 3 emissions was less prominent in discussions, efforts like transitioning from gas to electricity in operations were highlighted as steps towards reducing direct emissions and enhancing sustainability.
- **Manufacturing processes and environmental impacts:** The sector's focus on sustainability was evident in initiatives to move towards more sustainable energy sources and improve waste management practices, demonstrating a systematic approach to enhancing operational efficiency and environmental stewardship.
- **Collaboration and innovation for sustainability:** The emphasis on collaboration within the sector and with external recycling entities points to an integrated approach to advancing sustainability. The potential of electric arc furnace technology to revolutionise steel recycling practices was noted as a significant innovation towards reducing emissions and promoting circularity.

8.7. Sub-sector conclusions

Metals manufacturing in New Zealand is dominated by steel and aluminium production at Tiwai Point in the Southland and Glenbrook near Auckland. Smaller producers of non-ferrous materials, including gold, copper, and brass, were observed in Otago, Waihi, and Auckland. Downstream product manufacturing is more dispersed across New Zealand.

From our top-down assessment, emissions were concentrated in a few high-impact companies, emphasising primary/virgin metal production. Decarbonising these processes requires significant capital spend on emerging technologies, and long-term strategic roadmaps to support it. This is especially challenging for NZAS aluminium production, given the commercial uncertainties in this sub-sector.

Our bottom-up assessment of steel production identified a significant contribution to emissions from fossil fuel use and feedstock production. We noted a range of developments geared towards increasing metal recycling rates in New Zealand, notably the electric arc furnace in Glenbrook, due to come online in 2027, and Tiwai Point, the latter still facing an uncertain future. Again, a range of smaller recyclers were observed geared towards smaller volumes of non-ferrous metals.

Compared to other product categories, such as paper and polymers, the common carrier metals (iron, aluminium, magnesium, titanium, tin, nickel, copper, lead, zinc, chromium and manganese) can be recycled multiple times with minimal quality loss. Given this opportunity, the NZ industry lacks large-scale product circularity compared to overseas markets. Much of the functionality of metals in service within New Zealand and internationally derives from alloying elements added to these carrier metals and these elements are commonly diluted through the recycling process.

With the planned publication of a New Zealand critical minerals list later this year, a focus on applications including critical minerals is likely to become core to managing supply risks and identifying applications where circular economy principles can help to mitigate these risks. Given the recycling losses of many critical minerals, strategies are likely to need to focus on enhanced segregation, service life extension and reuse to decouple from these risks.

Wastes from metals production have been utilised in low-value applications, such as melter slag being used as aggregate, but opportunities exist to valorise higher-priced commodities such as vanadium or titanium.

Increasing the circularity of materials in this sector is a significant strategy for local decarbonisation, although it does displace these materials from entering offshore recycling streams. This means that domestic emissions reductions do not map to global reductions.

In the NZ context, suppliers in the non-ferrous market segment are already sourcing their materials from recycled stocks, and the upcoming EAF project at NZ Steel will further develop this strategy for the metals sector more broadly once it is commissioned in 2027.

9. Chemicals and refining sub-sector

9.1. Sub-sector overview

The chemicals and refining sub-sector covers the manufacturing of petroleum and coal-derived products, and basic chemical and chemical product manufacturing. These include methanol, fertiliser and pesticides, industrial gases, resins and rubber products used for plastics manufacturing, artificial fibres, medicines and pharmaceuticals, cleaning products, cosmetics, photographic chemicals, and explosives.

Large businesses operating in this sub-sector across New Zealand create hubs for employment and concentrations of product being manufactured in one area. New Zealand's only oil refinery is located in Northland at Marsden Point, and was decommissioned in 2022. It is now a terminal facility, responsible for the import, storage, testing and distribution of refined transport fuels. Methanol production is centred in Taranaki across two plants, with one at Motunui and one in the Waitara Valley.

The sector has experienced degrowth from 2018-2022 with compound annual growth during that period at -15.8%. Two key reasons for this were the closure of Marsden Point and the mothballing of Methanex's Waitara Valley plant. NZ exports a significant amount of methanol from steam-reformed natural gas as well as ethanol produced from casein (dairy protein), with total exports of $2.2 billion in 2019 (of all basic chemicals and chemical products).

NZ imports large quantities of crude oil and refined petroleum fuels, most of the basic chemicals, and virtually all the polymers required to produce polymer and rubber products. There are also many other basic chemical products imported which compete directly with locally manufactured products. This amounted to a total import volume of $6.4 billion in 2019.

Primary activities in this sub-sector include the manufacture, importation and distribution of basic chemicals that are produced and sold in bulk within the chemicals industry (where they are further manufactured into downstream products), the production of polymers from crude oil (i.e. polypropylene and polystyrene as examples), and end uses of products such as fertilisers, pesticides, cleaning compounds, construction chemicals, and surfactants.

Methanol produced in New Zealand by company Methanex is a notable player in the chemicals and refining sub-sector. It is used in many products across the New Zealand advanced manufacturing sector, including chemical end uses (paints, fabrics, building materials,) high-tech applications, pharmaceuticals, and medical equipment. However, we note most of the product is exported. Methanex state 45% of their product is used for energy applications, and 55% as a feedstock for manufacturing.

Products emerging from the chemicals and refining sector first come from primary distillation of crude oil, leaving LPG and petrol. Aviation fuel and diesel come from the same process but are collected from different densities from the production column. Hydrocarbon long residue is recovered for further treatment (through vacuum distillation) and cracking where it is converted to form liquid fuels or bitumen, and liquid fuels go through a desulphurisation and benzene-recovery processes before they can be sold for use.

Table 8 Examples of chemical and refining businesses in NZ

Chemicals	Refining
Basic chemical: Aakland Chemicals *Basic Polymer: Nuplex Industries* *Fertiliser and Pesticide: Ravensdown Fertiliser* *Pharmaceutical and Medicinal: Douglas Pharmaceuticals, Sheiling Laboratories, New Zealand Pharmaceuticals* *Cleaning Compound and Toiletry Preparation: Trilogy, Marketing Chemicals Limited* *Other basic chemical: RedBull Powder Company, Prime Explosives*	*Petroleum: Channel Infrastructure (previously Marsden Point Oil refinery)* *Coal: Bathurst Coal Limited*

9.2. Top-down assessment

9.2.1. Greenhouse gas emissions

On a top-down consumption basis, the chemicals and refining sector is the largest emissions source across the NZ manufacturing sector. This is largely influenced by the petroleum refining and coal product manufacturing sub-sector which has a very large consumption-based emissions footprint. It is important to note the effect of the baseline year here, and that the sole source of petroleum refining emissions in NZ was the Marsden Point refinery in Northland, which closed in April 2022.

Completing this same analysis using updated 2023 data would then show a much lower (almost negligible) production-based emissions figure. The nature of consumption-based emissions accounting means that product consumed by NZ residents is accounted for, even if it is not produced locally. This means even with the closure of Marsden Point and the cessation of domestic liquid fuels production, the demand for petrol, diesel, and kerosene still exists. Therefore, we would expect the consumption-based figure to be roughly the same, if not larger, in modern assessments.

Furthermore, this reliance on international imports may introduce supply chain reliability and resilience risks. Recent examples for this include the blockage of the Suez Canal by the Ever Given in 2021, the ongoing reduction in throughput in the Panama Canal due to drought, and the reduction in throughput through the Red Sea/Bab-el-Mandeb Straight due to Houthi attacks on shipping in late 2023/early 2024.

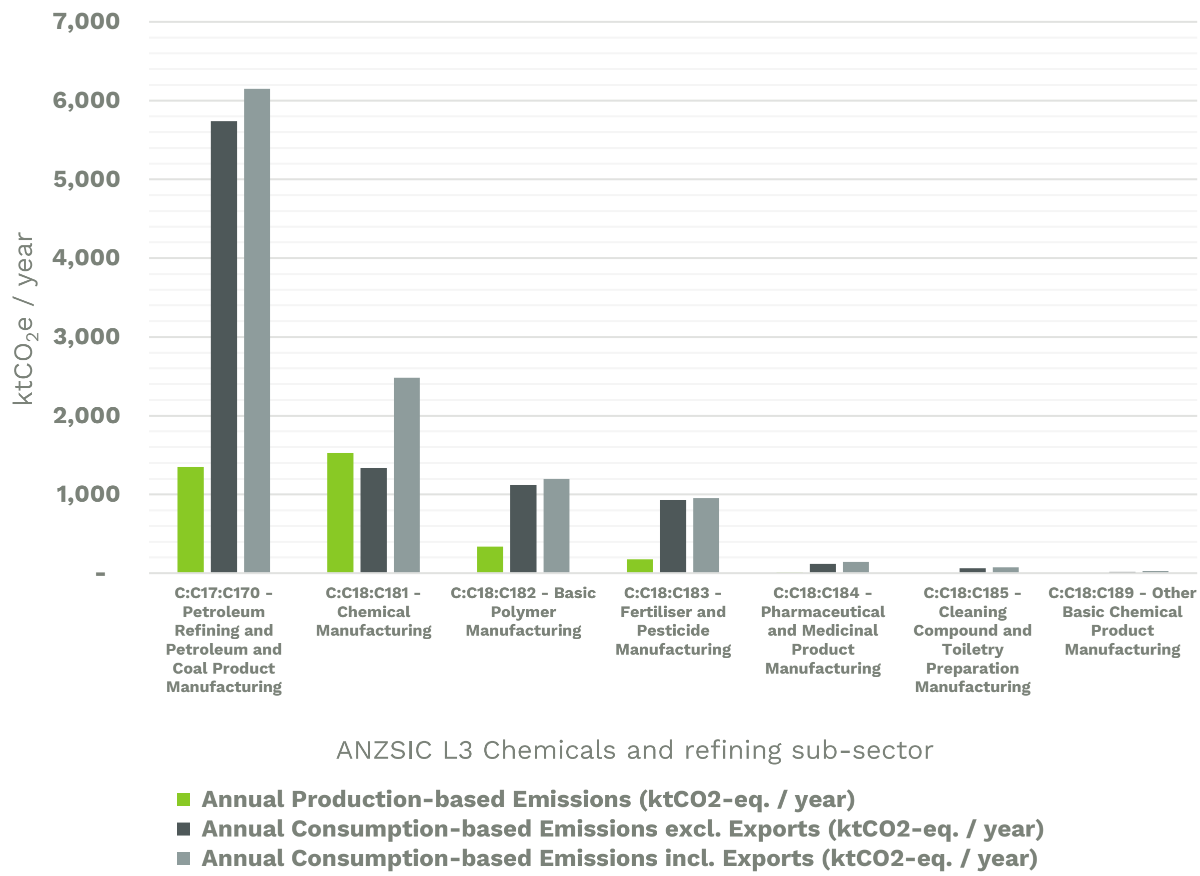

Figure 48 Annual production and consumption-based emissions from the chemicals and refining manufacturing sector (ktCO_2e / year), 2019 baseline

Although NZ's fuel imports are not directly impacted by these events, the events do have knock-on impacts across global supply chains. If bypass routes add 10-15% to a journey time, the effective utilisation of a ship goes down, and prices go up. In a worst-case scenario, events like this could have severe impacts on NZ's ability to fuel its vehicle fleets and manufacturing sectors. In addition to stockpiling, there are opportunities to reduce this risk through fuel switching and domestic alternative fuel production, which is linked into circular economy initiatives such as biofuels and biogas, or producing energy from biogenic waste materials.

The second most significant sector on a production basis is the basic chemical manufacturing sub-sector. The largest player in this sub-sector is Methanex, who use around 45% of New Zealand's natural gas supply to produce methanol, primarily for export (Methanex, 2019). This is a highly fossil-fuel-intensive process, using natural gas both for process heat and as a feedstock. There is a growing global demand for methanol. However local growth is limited by NZ's natural gas reserves, which have been declining.

Petroleum is a difficult sub-sector to decarbonise due to its interconnectivity across all other sectors. Unlike many other sectors mentioned in this report, it isn't as easy as decarbonising the manufacturing fuel source and expanding electricity generation capacity to reduce emissions from this sector. This is a more interlinked issue which requires transitioning entire fleets to alternative fuel sources and introducing entirely new supply chains to service them.

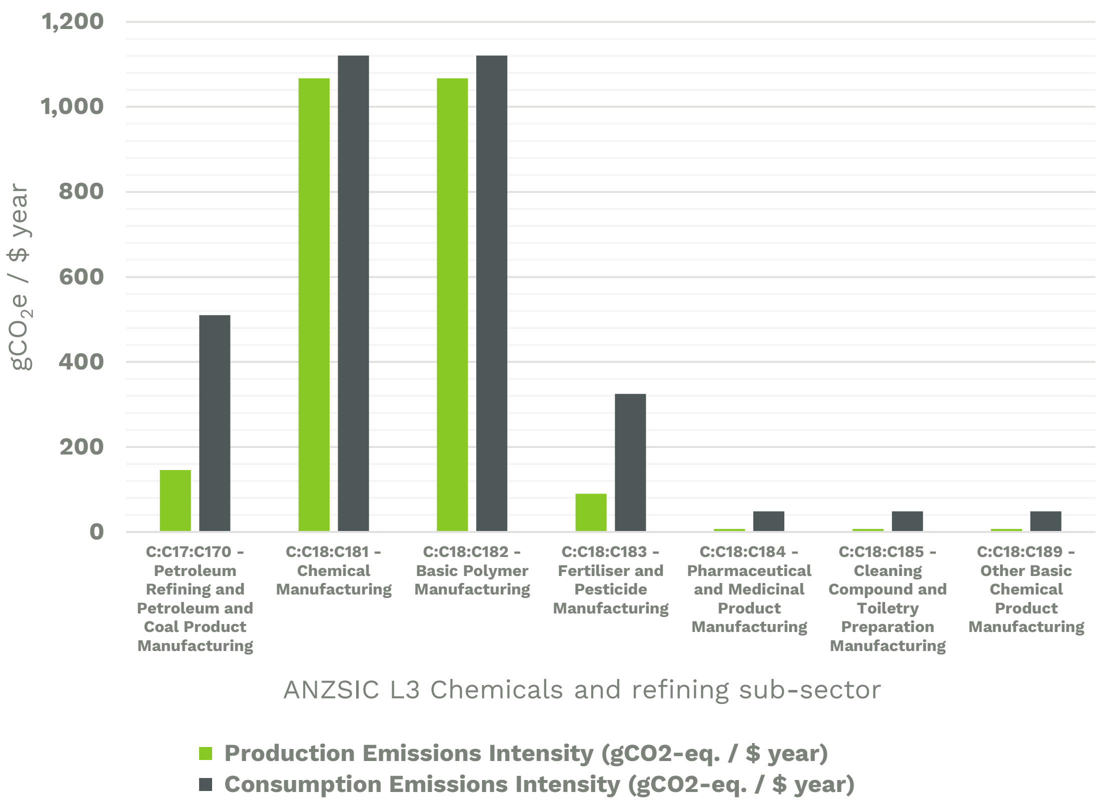

Figure 49 Production- and consumption-based emissions for the chemicals and refining manufacturing sector (gCO_2e / dollar - year), 2019 baseline

Looking at the emissions intensities of the chemicals and refining sector, we see that even though petroleum refinery dominated the emissions totals, it has a lower intensity than other types of chemical manufacturing. Chemical and basic polymer product manufacturing have much larger emissions intensities but end up smaller as emissions totals due to the lower demand for these products. This large intensity could be due to the widespread use of natural gas for processing and manufacturing in these sub-sectors, supported by the large production-based emissions intensity. The small increase to consumption-based emissions may indicate a very small emissions footprint of the supply chain for these sub-sectors, or a very small amount of imports.

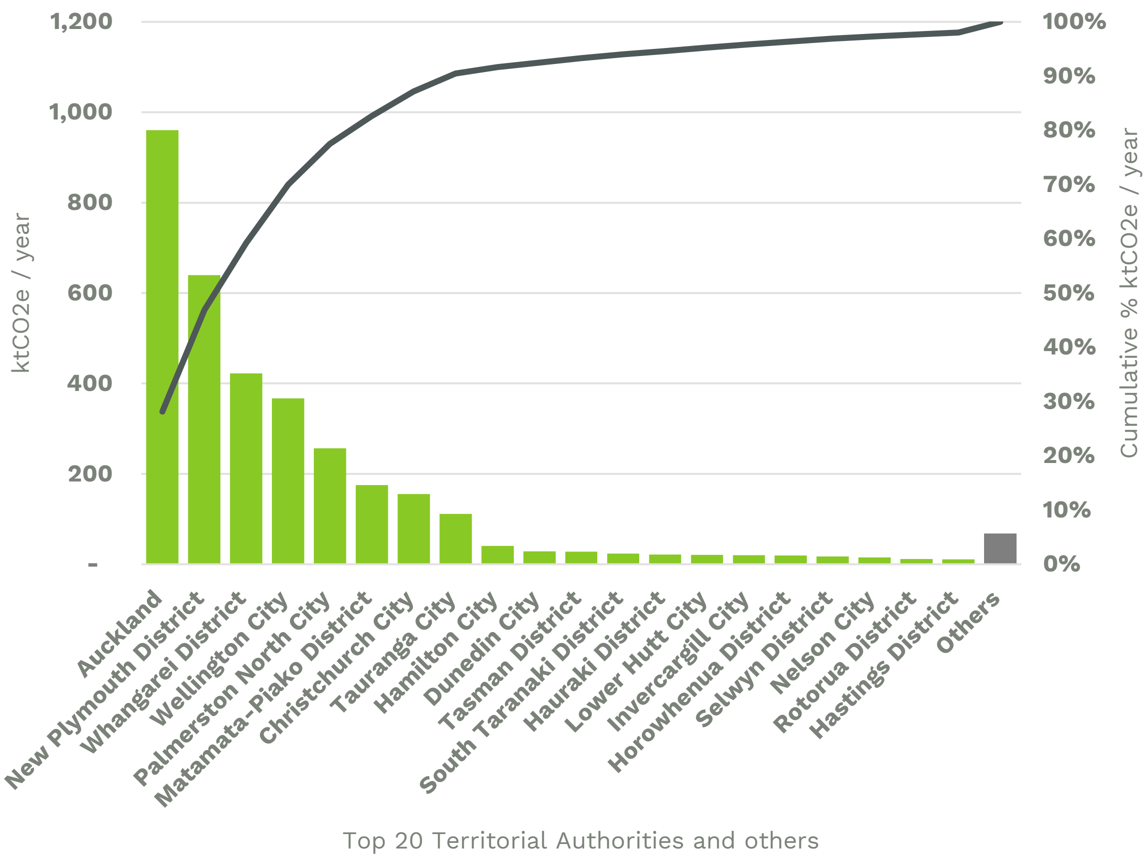

Figure 50 Annual production-based emissions from the chemicals and refining manufacturing sector across NZ territorial authorities (ktCO₂e / year), 2019 baseline

While Auckland is still the largest contributor to this sector as with the other manufacturing categories, other regions are also relevant here. Together with New Plymouth and the Whangārei district, both centres for the gas and refining sector, the three make up almost 60% of the national total emissions for this sub-sector.

Overall, we see a few regions with a large contribution to the emissions from the chemicals and refining manufacturing sector. We see chemicals and polymer products have a very large production-based emissions footprint, while petroleum refining and coal products is dominated by supply chain emissions indicated by its larger consumption-based emissions. Other chemical sub-sectors are much smaller in comparison, while the overall sector total is the largest out of all advanced manufacturing sectors.

9.2.2. Waste

Focusing on potential chemical and refining manufacturing waste generation, the following associated streams are outlined in Table 9.

Table 9 Chemical and refining waste characterisation by waste material composition, SWAP categories

	Chemical and refining	***Identified source examples***
Organics	✓	From bio-based resource inputs
Cardboard and paper	✓	Packaging
Timber	✓	Packaging
Rubble/concrete (incl cleanfill)	-	-
Potentially hazardous	✓	Contaminated packaging, degraded/rejected product, unused/expired chemical
Plastic	✓	Packaging
Metals		
Textiles	✓	Personal protective equipment
Nappies and sanitary	✓	Personal protective equipment
Glass	-	-
Rubber (incl tyres)	-	-

Through qualitative resource flow scan activities, we identified potential waste outputs associated with production. The chemicals and refining sector is diverse in terms of inputs and processes used to produce end products, notable areas include fuel and natural gas production, agricultural fertiliser and pesticides, pharmaceuticals, chemicals, and synthetic resin production. Further, NZ is only actively involved in limited areas of the supply chain, with key inputs being import-dominated. Due to the nature of this sub-sector, 'potentially hazardous' waste is identified as a key waste output, which would need to be mitigated in line with resource contenting requirements for treatment. Personal protective equipment and packaging remain a consistent waste stream primarily due to safety requirements. Depending on the product, outputs can include biowaste and heavy metal sludge. Contaminated packaging and unused/expired chemical waste has also been identified.

9.3. Bottom-up assessment

9.3.1. Qualitative resource flows

Part of the resource and waste mapping for the chemicals and refining sector included the development of material flow diagrams at ANZSIC Level 4. These identify the key product, input resources, and output co-products, by-products, and waste products. It also identified opportunities for circular resource flows across ANZSIC Levels 3 and 4. Sub-sector material flow diagrams completed to date include:

- A combination of C1821 Synthetic rubber Tyres and C1914 Tyres (Figure 51)

These flow diagrams are shown on the following pages. Overall, this exercise has identified some key findings and opportunities.

- By-products are typically utilised internally within ANZSIC Level 3 of chemicals and refining, e.g. petroleum refining by-product used for paraffin wax (Fawcett, 2013); used oil recovered and used through a product stewardship scheme as fuel in asphalt production plants (Sage, 2019); or activated charcoal used for hygiene products or supplements (Activated Carbon Benefits, 2024)
- Processing emissions can be reduced through pinch analysis and process integration methods of process heat recovery. Pinch analysis has been applied by the chemicals and refining, pulp and paper, and food and beverage sectors, but not widely (Atkins, Options to Reduce New Zealand's Process Heat Emissions, 2019). Switching to heat exchangers from shell-and-tubes is an opportunity for petrochemicals (Waste heat recovery, Alfa Laval)
- Waste products of synthetic rubber often circulate within the sub-sector, e.g. rubber seals and hoses recycled into crumb for adhesives, foam, paints, rubber compounds, and roading (Rubber Solutions, 2024); and polystyrene into compacted polystyrene or SL grade blocks (Koolfoam, 2023)
- Offcut or recycled synthetic fibre, rayon, nylon, and polyester materials can be reused into fleece with chemical recycling (Patagonia, 2022); to make felt blankets (Casey, Crowe, Pretorius, & Thompson, 2022, wh. 23)
- Recyclability of carbon-fibre is developing rapidly, for future use in carbon-fibre-reinforced products (MonkeyToe, 2021)
- Fertiliser, pesticide, essential oil, and pharmaceutical bio-waste can be used as bio-gas / energy (German Biogas Association, 2019)

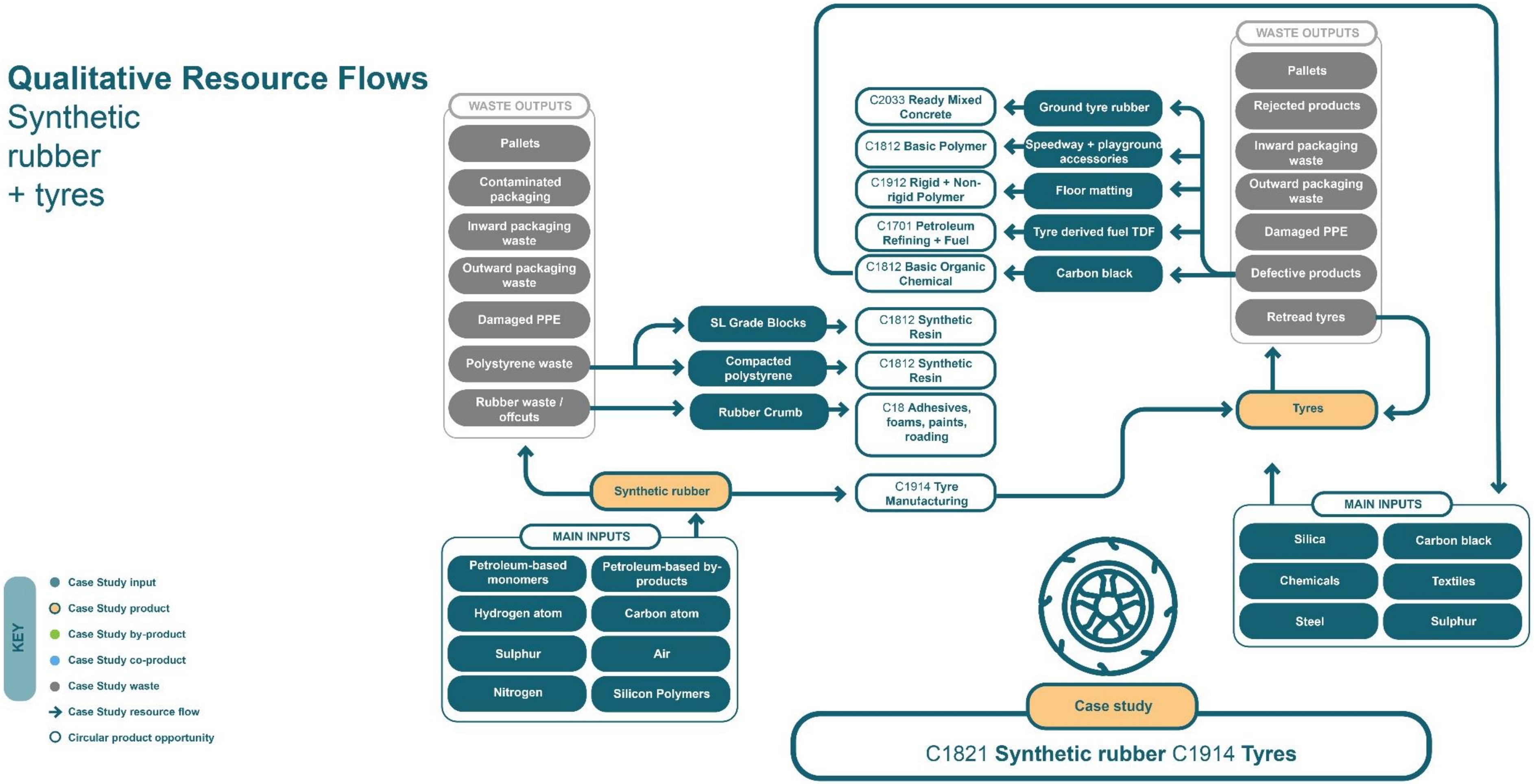

Figure 51 Resource flow map for Synthetic rubber (C1821) and Tyres (C1914)

9.3.2. Key material flows

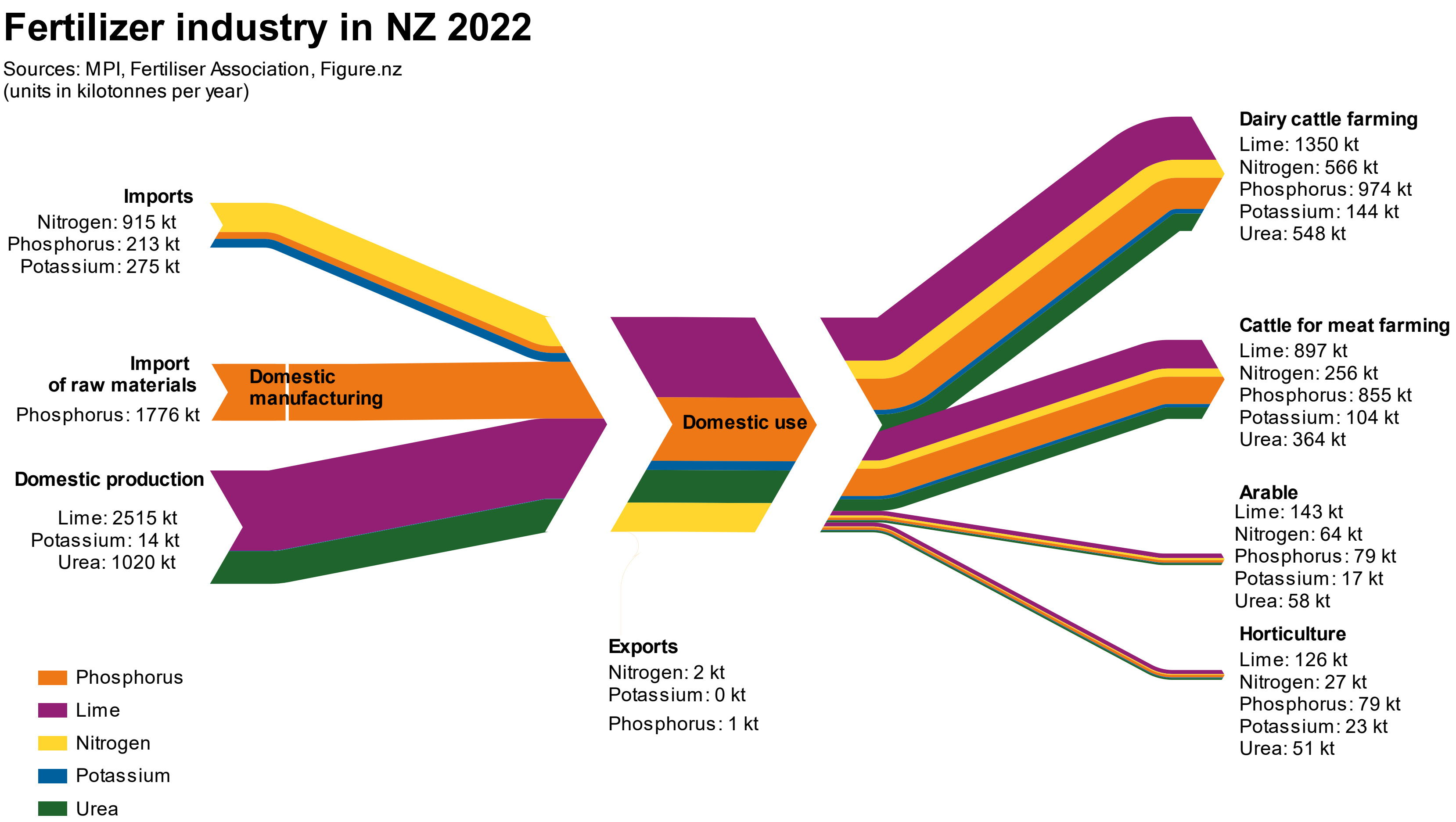

Figure 52 New Zealand fertiliser chemical flows (2019)

9.3.3. Hotspots identified

Figure 52 outlines the flow of various fertilisers from import or domestic production to their end use in different agricultural sectors. The key points identified were:

1. **Import reliance:** The industry relies heavily on imported nitrogen (915 kt), phosphorus (213 kt), and potassium (275 kt). A further 1,776 kt of phosphorus was imported to support the domestic manufacture of phosphate-based fertilisers.
2. **Domestic production:** A considerable quantity of lime (2,515 kt) and urea (1,020 kt) was produced domestically, indicating a strong domestic production base for these fertilisers. Domestically produced potassium was relatively minor at 14 kt.
3. **Dairy use:** The largest consumer of fertilisers was dairy cattle farming, which utilises significant quantities of lime (1,350 kt), phosphorus (974 kt), and nitrogen (566 kt), along with urea (548 kt) and potassium (144 kt).
4. **Cattle for meat:** The second largest consumer of fertilisers was farmed cattle for meat, which utilises significant quantities of lime (897 kt), phosphorus (855 kt) and urea (364 kt) as well as nitrogen (256 kt) and potassium (104 kt).
5. **Arable farming and horticulture:** use less overall but still rely on these inputs, highlighting the widespread dependency on fertilisers in New Zealand agriculture.
6. **Exports:** Compared to the imports and domestic consumption, exports of fertilisers are minimal, with only 2 kt of nitrogen and 1 kt of phosphorus being exported.

The Sankey diagram reflects the critical role of fertilisers in New Zealand's agricultural productivity, with importation being a significant aspect of the industry. It also points to the potential impact of these fertilisers on the environment and the importance of nutrient management practices to ensure sustainable agriculture. The limited exports compared to the volume of imports and domestic production suggest that New Zealand's fertiliser industry is largely inward-focused, catering to the substantial needs of its agricultural sectors. Given the nature of phosphate production and its generally non-renewable extraction, a dependency on imported phosphates could be seen as a potential supply chain vulnerability with potentially significant impacts on the agricultural sector.

9.4. Location

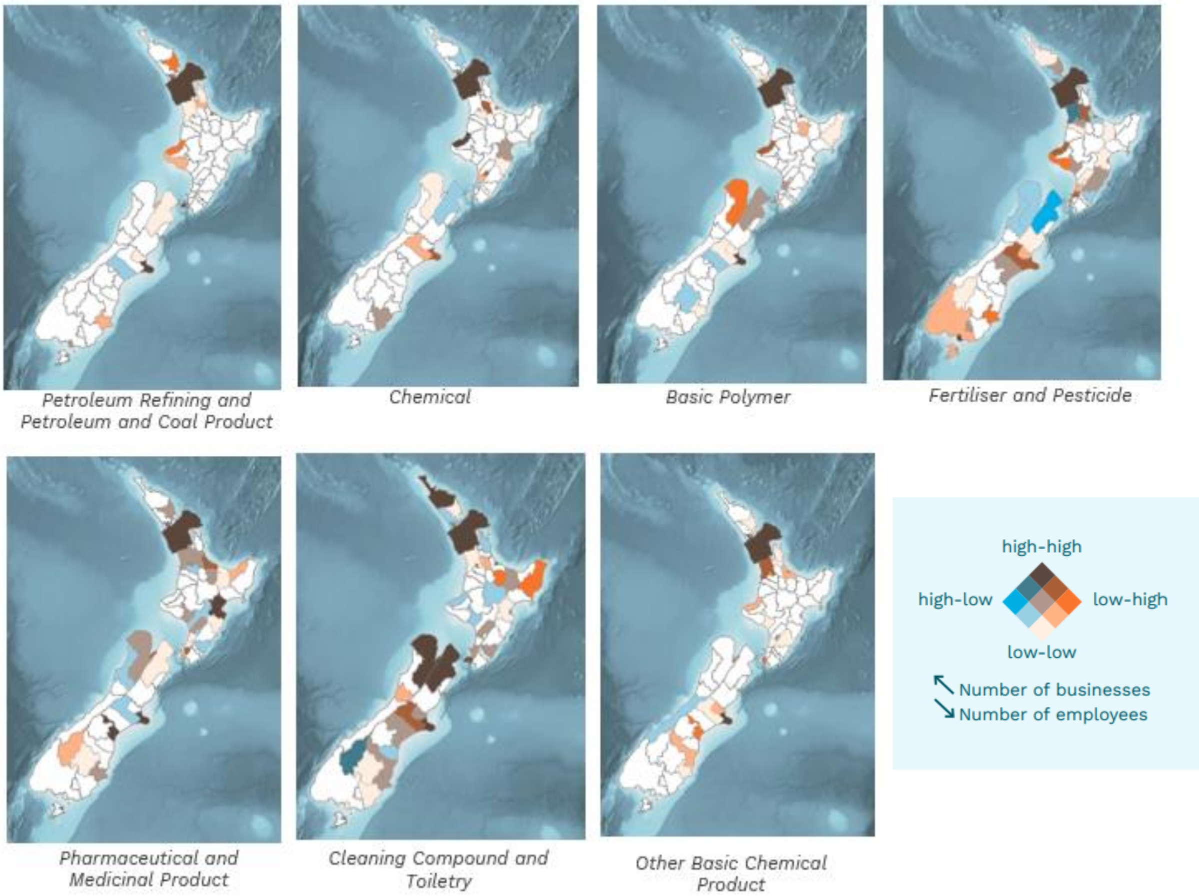

Figure 53 Manufacturing activity location – chemicals and refining ANZSIC Level 3 by territories, 2019

Chemicals and refining manufacturing activity is very active in Auckland and Christchurch. Although there are some locations of regional spread such as Waimakariri District, Waipa District, Timaru District, Selwyn District, they are not as popular to operate from.

Although the other manufacturing sectors see more spread across the country, petroleum and coal product manufacturing is rather condensed in several key districts, Auckland, Christchurch, Whangārei District, Tauranga City, Lower Hutt City, and Wellington City. Marsden Point was the only oil refinery in NZ, found in Whangārei.

Basic chemicals and chemical product manufacturing activity is quite different to petroleum and coal product manufacturing as there is more regional area activity. Although Auckland is still the location with majority of the activity it is followed by Christchurch, Tauranga City, and Hamilton City.

9.5. Data gaps

Specific emissions data from Methanex was not identified in the bottom-up analysis. Given the importance of this company for this sector, especially given the closure of the Marsden Point refinery, it represents a significant gap when aligning the top-down and bottom-up emissions profiles.

The top-down data set was limited to the sub-sector level, and so further conclusions could not be drawn here. The bottom-up data only included information on the fertiliser sector, meaning other conclusions could not be drawn for sub-sectors including basic polymer production, pharmaceuticals, or other basic chemical manufacturing.

Bottom-up data was limited to the masses of fertiliser imported and consumed within NZ, and did not consider the emissions associated with their production and use. Given the different production processes associated with fertiliser, where some products are fossil-derived, and others are mineral-derived, a mass balance does not necessarily link to carbon emissions.

Quantitative data on waste from the chemical industry was not able to be identified, with qualitative information from flow mapping suggesting areas for future focus.

9.6. Stakeholder perspectives

Workshop participants noted that while the data provided useful insights into emissions from different chemical and refining processes, there were notable gaps in granularity and specificity. This included the aggregation of data which complicated the ability to distinguish between impacts of different chemicals, underscoring the need for a more detailed emissions breakdown and waste stream data.

The discussion around primary manufacturing emissions, especially concerning the reliance on coal and natural gas, was insightful but expected. The potential for enhancing domestic recycling capabilities to mitigate scope 3 emissions related to imported chemicals underscored the sector's environmental impact concerns and the necessity for a detailed analysis of supply chain emissions.

Participants identified a need for more precise data on recycling processes, waste management of chemical by-products, and the environmental impacts of different disposal methods. Suggestions for bridging data gaps included leveraging customs data for insights into chemical imports and engaging with entities like Toitū Envirocare to access lifecycle assessments.

Opportunities for improving the sector's circularity included enhancing recycling at source, developing business models that promote chemical product reuse, and exploring bio-based chemicals as sustainable alternatives. The industry's transition towards a circular economy requires clearer regulation, better data, and support for sustainable material R&D.

Sector-specific practices and challenges:

- **Waste and recycling management:** The sector's practices, such as the disposal and recycling of chemical waste and managing wash water, highlight efforts to comply with regulatory frameworks and reduce environmental impact. The engagement with carbon management systems points towards broader sustainability efforts, although more direct connections with the waste/resource recovery sector could enhance sustainability.
- **Emissions management:** The focus on tracking carbon emissions across scopes 1, 2, and 3 indicates an ongoing effort to understand and minimise the carbon footprint. Challenges related to commercial sensitivities and competitive knowledge sharing were noted, underscoring the need for collaborative data sharing and emissions reduction approaches.
- **Manufacturing processes and environmental impacts:** Insights into the sector's reliance on imported raw materials and the significant energy requirements for chemical processes highlighted logistical and environmental challenges. The transition towards electricity and exploring decarbonisation pathways were discussed as strategies to address these challenges.
- **Collaboration and innovation for sustainability:** The importance of industry collaboration and sharing non-competitive data were emphasised as mechanisms for improving sustainability practices. The sector's exploration of decarbonisation pathways and sustainable chemical production methods reflects a commitment to environmental stewardship and operational efficiency.

9.7. Sub-sector conclusions

The chemicals and refining sub-sector includes a diverse range of high value manufacturing, spanning fuels, polymers, fertilisers, pesticides, medicines, cosmetics, detergents and industrial chemicals. The sector has experienced degrowth between 2018 and 2022, shrinking by 15.8% with a corresponding decrease in R&D expenditure of 13.67%. This seems likely to reflect a longer-term decline in the sector and a decrease in the number of chemicals and refining businesses in New Zealand. Nevertheless, the sub-sector captured 12% of manufacturing foreign direct investment between 2021-2022 with pharmaceuticals and cosmetics notable growth areas. Auckland, Wellington and Tauranga were noted as significant focal points for this sub-sector.

In 2019, New Zealand imported $6.4 billion of fuels and chemicals, many of which compete with domestically produced alternatives and may represent an opportunity to reshore or expand production. Such changes would need to be mindful of the resulting shift in emissions and our ability to reduce global emissions as a result. The potential for increased exposure to international supply chain risks from this shift was noted.

Our top-down assessment noted that this sub-sector was the most significant in emissions, with significant consumption-based emissions linked strongly to petroleum and coal. The 2021 closure of the Marsden Point refinery will not have been reflected in the 2019 data used by this work. We would expect an update of this analysis using 2024 data to indicate negligible production-based emissions as a result, with a potential shift to even greater consumption-based emissions.

The most significant sub-sector on a production emissions basis is basic chemical manufacture, dominated by Methanex. Although this could not be confirmed using bottom-up analysis, the changed landscape following the Marsden Point closure emphasises the importance of this producer for this sector.

From a waste perspective, the sector's diversity made analysis particularly difficult, but we noted the potential for multiple ‘potentially hazardous’ waste streams and dissipative losses through the environment and waterways as well as through organic biowaste and sludge. The disposal of contaminated packaging and unused chemical waste were also noted as likely sources of problematic waste.

Our bottom-up analysis of the New Zealand fertiliser industry similarly highlighted a heavy import dependence both for fertilisers and for raw materials used in domestic production inside New Zealand. Strong links to the dairy and meat farming sectors were illustrated, indicating potential supply chain risks linked to highly concentrated sources of phosphorus, for example. Stakeholder engagement reinforced the import dependence of the sector as an underlying concern for the sector more generally.

Stakeholder engagement also highlighted the industry's efforts to improve sustainability practices and the role of regulatory frameworks in driving this change. Stakeholders also highlighted a general shift to low-carbon energy and decarbonisation pathways.

10. Plastics and rubber sub-sector

10.1. Sub-sector overview

Firms operating in the plastics sub-sector face significant competition from imported products. China is the major source of competitive plastic imports for downstream manufacturers in New Zealand due to the lower labour and overhead costs, which can be passed onto customers through lower prices. Competition in the plastics products market segment is mostly between manufacturers. They tend to be small outfits producing short production runs and do not compete on their ability to generate economies of scale, but instead on their ability to deliver the right quantity and quality of product within specified timeframes.

Plastic products range from containers and cling film to children's playground components, and pipes and fittings used in construction. Rubber products can range from civil, construction and industrial use, to agricultural goods, to household goods such as hoses and gumboots.

Most firms that operate locally in this sub-sector produce rigid and semi-rigid plastic products and are small to medium enterprises that focus on specific product offerings and their geographical markets. Examples include Hangar Holdings (plastic products such as food containers, bottles, and storage boxes), Custom-Pak Plastic Products (plumbing products, elastomer products, a polymer and rubber extrusion company), PACT group (packaging, including wash plant and recycling capability), Skellerup (technical polymer products), and Marley New Zealand (a manufacturer of extruded and injection moulded PVC and PET products).

Manufacturing processes include injection moulding, extrusion, or roto-molding using heat transferred through steam, hot water or hot oil, typically generated onsite using a boiler or furnace. Different manufacturing processes throughout this sub-sector require different temperatures depending on the melting point of polymers used but are generally low (less than 100°C) or low-to-medium (100°C - 300°C). Lower-temperature heat processes are generally easier to decarbonise than higher-temperature processes.

Synthetic polymers include polyolefins that are typically imported, although there is some local manufacturing of resins and rubber (polyethylene, polypropylene, polyvinyl chloride) linking this sub-sector with chemicals and refining. Component plastics products are both manufactured within New Zealand and imported for further processing, including flexible, rigid and semi-rigid plastics, rubber products, synthetic fibres, foam products, paints and coatings, lubricants and adhesives, and sealants.

With the recent shift to digitally enabled 3-D printing (additive manufacturing), the market for polymers used in additive manufacturing has experienced significant growth and it is possible that the market will evolve towards tailored polymers for the technology. This could see innovation and commercial opportunities for firms that make photopolymers, high-performance thermoplastics and other chemicals used in these processes. Mass production has given way to mass customisation, delivered through multiple channels. This is aimed at adding value and integrating into customers' businesses.

The plastic manufacturing industry faces continued pressure from the government and consumers to address and reduce problematic single-use plastics. Regulatory changes have influenced what this sector produces in some areas e.g. Waste Minimisation (Plastic and Related Products) Regulations 2022 prevented retailers from providing, selling or manufacturing targeted single-use plastic products and packaging in New Zealand, with phase 1 implemented in 2023 and further bans through phase 2 in 2025. Producers have also been aligning packaging design with nationally standardised kerbside collection plastic specifications or other product stewardship requirements e.g. Soft Plastics Recycling.

Rethinking Plastic in Aotearoa New Zealand produced by the Office of the Prime Minister's Chief Science Advisor makes several recommendations on how to minimise the negative impacts of production and consumption of plastic. This places a heavy emphasis on the waste hierarchy and '6Rs' (rethink, refuse, reduce, reuse, recycle and replace). It also identifies the need for improved plastics data to help reduce and better manage plastic waste flows associated with products and packaging - in particular mitigation of leakage into the environment.

10.2. Top-down assessment

10.2.1. Greenhouse gas emissions

For plastics and rubber, we see minimal production-based emissions, which indicates the domestic economy for this sector is very small. Imported products seem to be the driver behind consumption-based emissions for both plastics and rubber and there is a very small number of exports. These products are possibly produced much cheaper and more efficiently overseas so there is little need to produce them domestically, or it could be too difficult to stay price-competitive with international products.

This import bias makes decarbonising the sector difficult as most of the emissions footprint is in the supply chain of imported goods. Ways to reduce this footprint may include legislative levers such as controlling what types of products can enter the country, and matching recycling and waste management infrastructure to the types of plastics and rubber entering our waste streams. When looking at emissions intensities we see the difference in production- and consumption-based emissions might not be all attributed to import bias, and that the supply chain emissions are so much larger than the final manufacture itself.

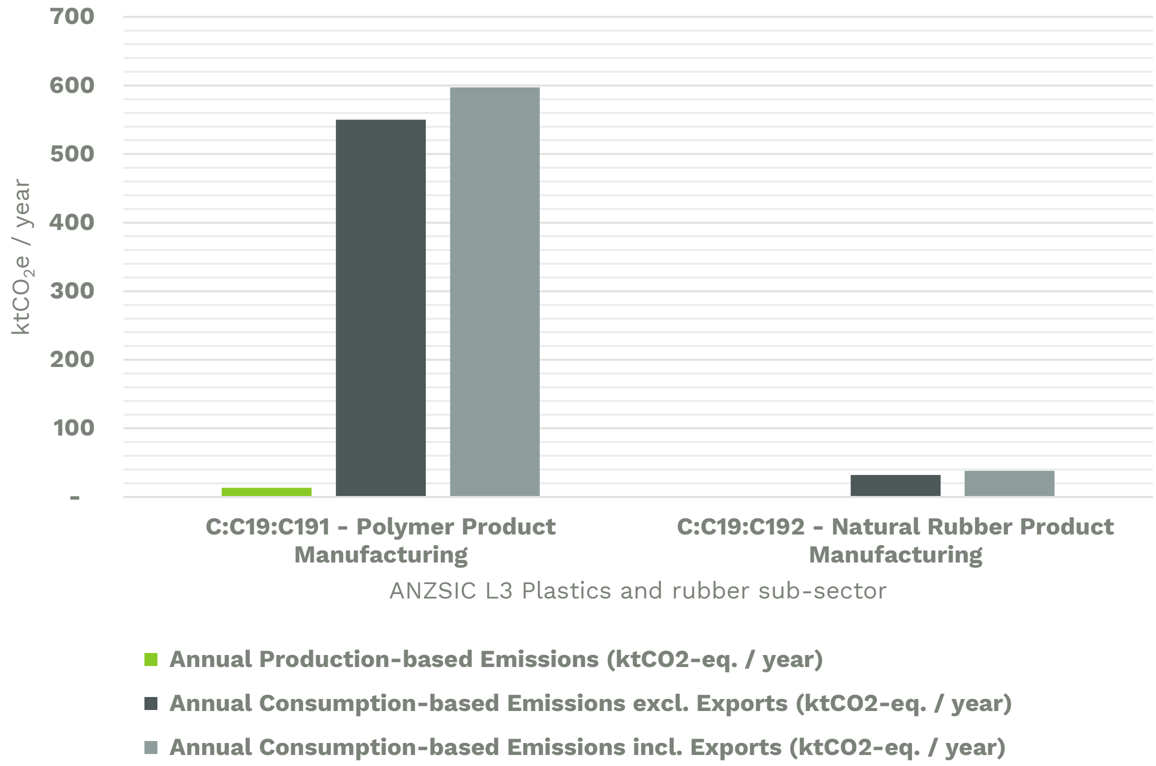

Figure 54 Annual production- and consumption-based emissions from the plastics and rubber manufacturing sector (ktCO_2e / year), 2019 baseline

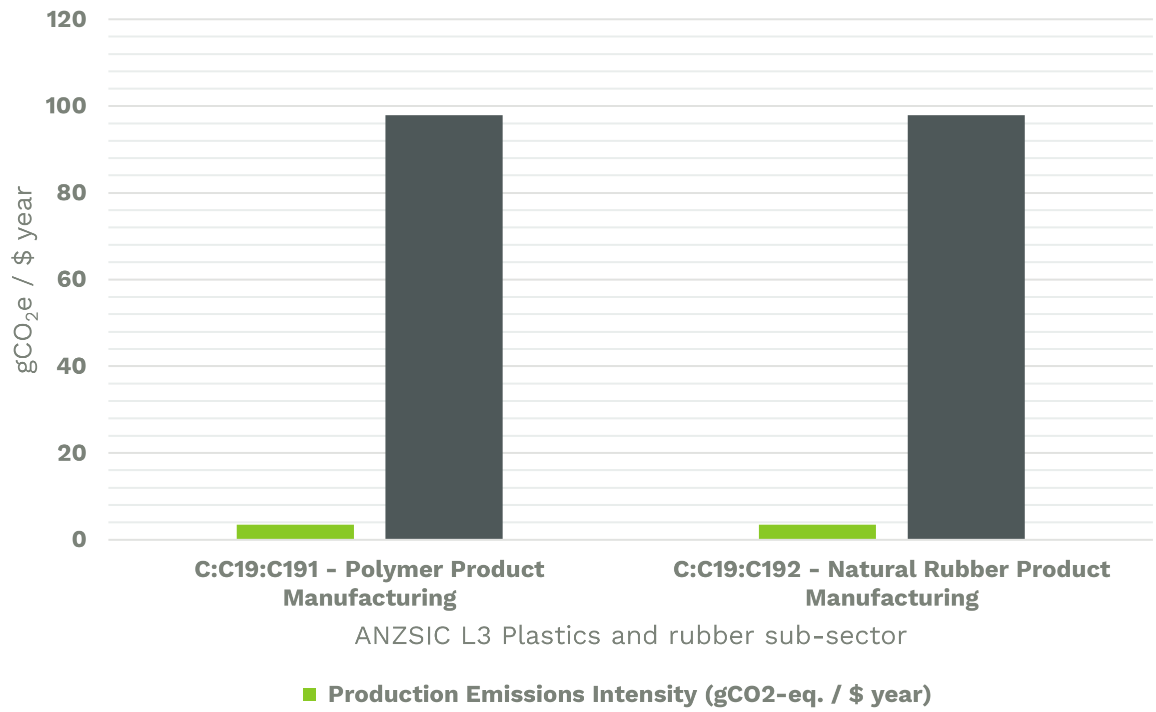

Figure 55 Production- and consumption-based emissions intensities for the plastics and rubber manufacturing sector (gCO_2e / dollar - year), 2019 baseline

When looking at the chemicals and refining sector, we note the production emissions of basic polymers are relatively high. This may explain the large supply chain emissions for polymer products. The emissions intensities of these product-based (rather than raw material-based) manufacturing sub-sectors are low compared to many of the other sub-sectors looked at in this analysis. We propose the key opportunities here are around reducing the need for plastic-based products (especially single-use products), and closing the loop with the waste at end-of-life, rather than focussing on reducing the emissions intensity of manufacturing itself.

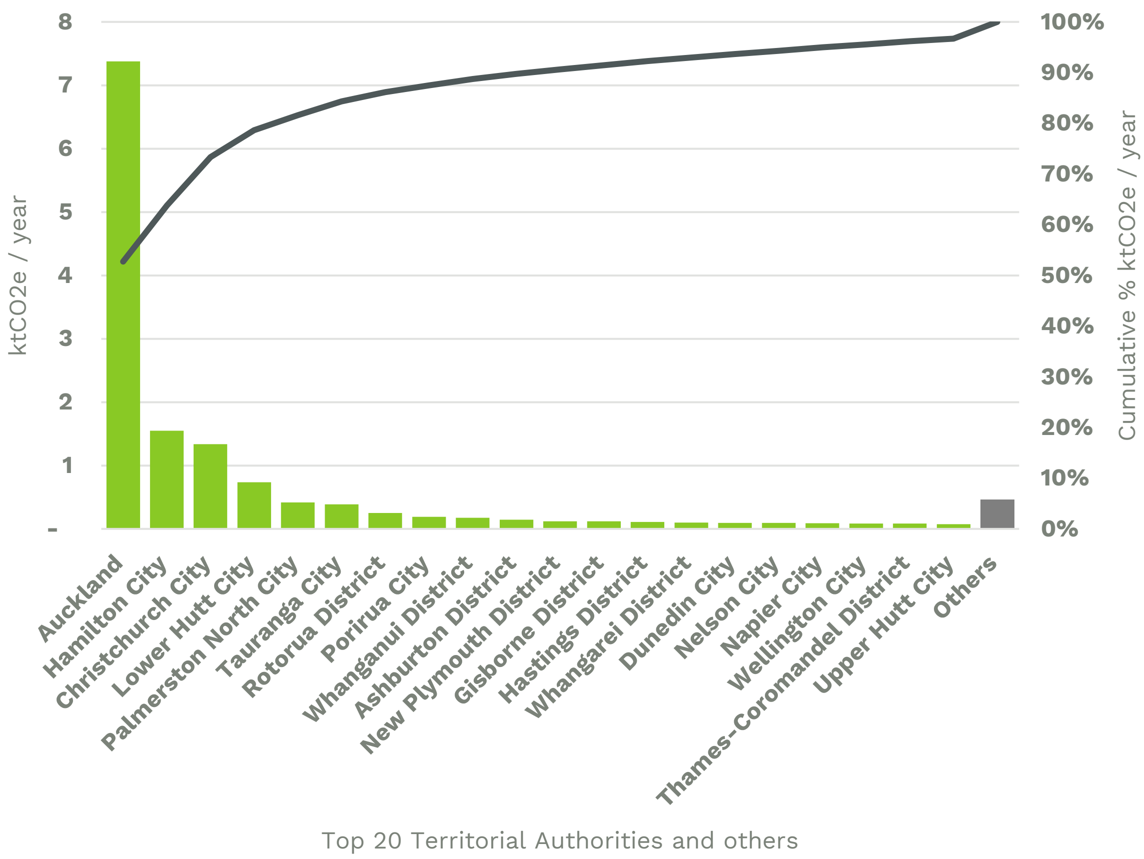

Figure 56 Annual production-based emissions from the plastics and rubber manufacturing sector across NZ territorial authorities (ktCO₂e / year), 2019 baseline

Auckland accounts for 53% of all emissions associated with plastics and rubber production. With such a high concentration in a single region, there may be an opportunity to reduce emissions and waste output from this sub-sector by concentrating development of infrastructure and systems in Auckland.

Overall, the plastics and rubber sector has a very large consumption-based emissions footprint, compared to purely production, due to a mix of large supply chain emissions and an import bias. Overall, the emissions intensities from both approaches are small in comparison to many other sub-sectors, while the overall emissions are substantial – indicating there is a large demand for these products in NZ. The opportunities for reducing emissions in this sector may lie in legislative changes and systems to reduce the number of types of materials coming in, and limit NZ consumption to lower emissions alternatives.

10.2.2. Waste

Focusing on potential plastics and rubber manufacturing waste generation, the following streams are identified as being associated as per table 10.

Table 10 Chemical and refining waste characterisation by waste material composition, SWAP categories

	Plastics and rubber	Identified source examples
Organics	-	-
Cardboard and paper	✓	Packaging
Timber	✓	Packaging
Rubble/concrete (incl cleanfill)	-	-
Potentially hazardous	✓	Solvents, unused/expired chemicals, used filters, pigments, recycling wash plant outputs, sludge waste
Plastic	✓	Offcuts, rejected product, packaging
Metals	-	-
Textiles	✓	Personal protective equipment
Nappies and sanitary	✓	Personal protective equipment
Glass	-	-
Rubber (incl tyres)	✓	Offcuts, rejected product

Through qualitative resource flow scan activities, we identified potential waste outputs associated with production. This involves the conversion of raw materials from chemicals and refining such as resins and additives as inputs into production. This means waste is largely associated with plastic, rubber and potentially hazardous streams. We note internal recycling practices are observed, including the reuse of offcuts.

10.3. Bottom-up assessment

10.3.1. Qualitative resource flows

Part of the resource and waste mapping for the plastics and rubber sector included the development of material flow diagrams at ANZSIC Level 4. These identified the key product, input resources, and output co-products, by-products, and waste products. The mapping also identified opportunities for circular resource flows across ANZSIC Levels 3 and 4. Sub-sector material flow diagrams completed to date include:

- C1912 Rigid + Semi-Rigid Polymers (Figure 57)
- A combination of C1821 Synthetic rubber Tyres and C1914 Tyres (Figure 51, chemicals and refining section)

These flow diagrams are shown on the following pages. Overall, this exercise has identified some key findings and opportunities.

- Flexible polyvinyl chloride (fPVC) and rubber produced from tyre retreads is upcycled into safety surfacing products, that can be recycled at end-of-life (Matta, 2022)
- End-of-life tyres are used as alternative fuels by Golden Bay Cement to create a low-carbon cement product (Golden Bay Cement, 2019)
- Carbon black is a waste product of tyres which can be regenerated and reused within production, cutting emissions up to 80% (TyreHub, 2024; LCANZ, 2019)
- Post-consumer HDPE is recovered and recycled into fence posts (Country Life, 2019), and culvert pipes (Hynds, 2024)

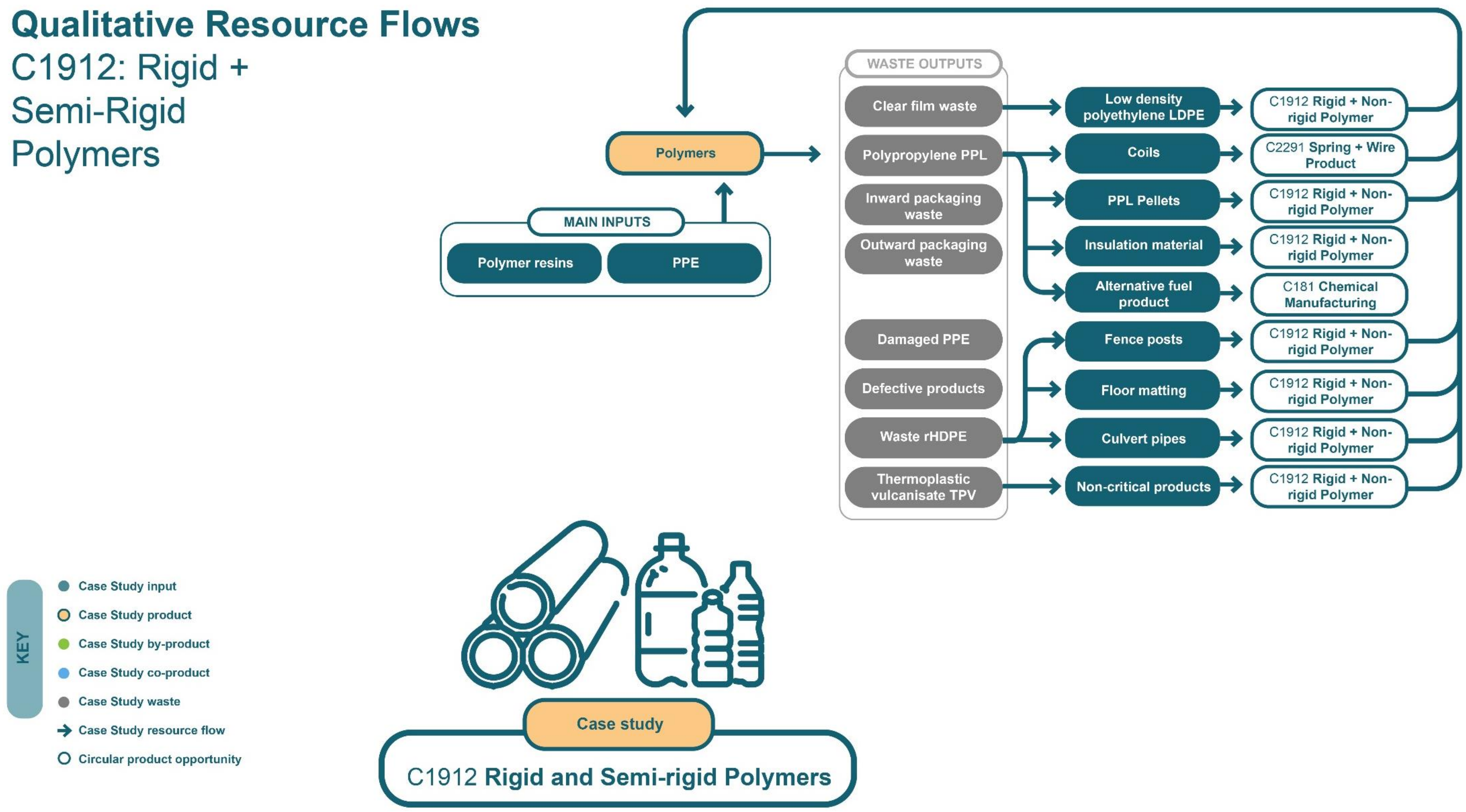

Figure 57 Resource flow map for Rigid and Semi-rigid Polymers (C1912)

10.3.2. Key Material Flows

Plastic production in New Zealand 2020
Source: Auckland Council, MBIE NZ, ME NZ, Office of the Prime Minister's Chief Science Advisor, Stats NZ, thinkstep-anz
(unit tonnes of plastics produced in 2020)

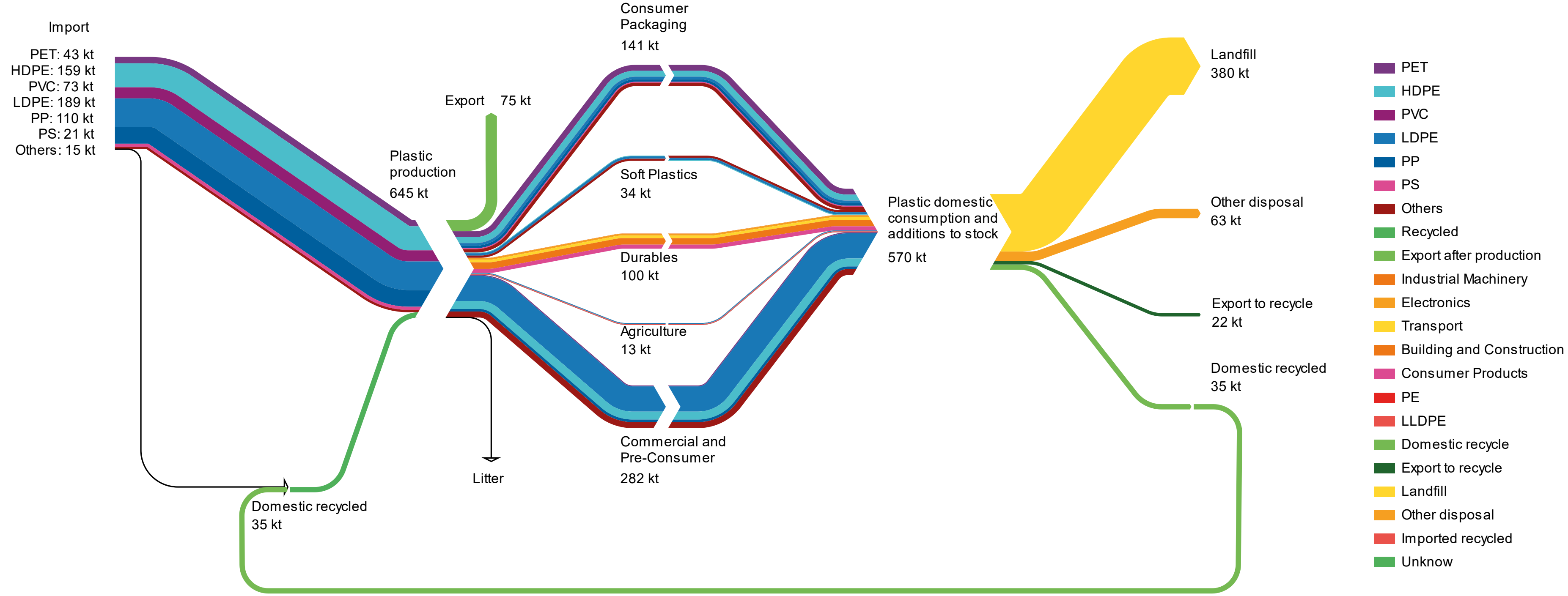

Figure 58 New Zealand flows of plastic (2019)

10.3.3. Hotspots identified

Figure 58 for plastic production in New Zealand in 2020 provides a detailed view of the country's plastic flow, from import and production to consumption and waste management. The key points identified were:

1. **Imports:** New Zealand imports a significant amount of plastics, with the largest imports being LDPE (189 kt), HDPE (159 kt) and PP (110 kt), followed by other types including PET (43 kt), PVC (73 kt) and PS (21 kt). The total import of various plastics amounts to 610 kt, highlighting New Zealand's dependence on external sources for these materials.
2. **Plastic production:** The domestic production of plastic stands at 645 kt, indicating a substantial local plastic manufacturing sector based primarily off imported feedstocks, with only 35 kt coming from domestic recycling.
3. **Domestic consumption:** The majority of produced and imported plastics goes into domestic consumption and additions to stock, totalling 570 kt. This indicates a high proportion of domestic usage within New Zealand.
4. **Exports:** Post-production, New Zealand exported 75 kt of plastics, suggesting some level of international competitiveness, specialised production capabilities or use as packaging for other exported goods.
5. **End-use sectors:** Plastics are primarily used in commercial and pre-consumer sectors (282 kt) and consumer packaging (141 kt). Other significant uses include durables (100 kt), soft plastics (34 kt), and agriculture (13 kt).
6. **Waste management:** A substantial amount of plastic in the New Zealand market ends up in landfills (380 kt), with a smaller amount being disposed of in other ways (63 kt). Compared to the landfill figures, the volume of plastics being recycled domestically is minimal (35 kt), and an even smaller amount is exported for recycling (22 kt).
7. **Litter:** The figure recognises that some plastics will end up as litter but we have been unable to identify the volumes associated with this flow. Other sources of microplastics, such as tyre wear, which are recognised internationally as being significant have also not been assessed.

This diagram illustrates New Zealand's plastic industry and reveals the challenges of managing plastic waste and recycling. The significant reliance on imports, combined with the high volume of plastic ending up in landfills, suggests opportunities for improving recycling infrastructure and reducing plastic waste through policies and incentives. The relatively small amount of plastic being recycled also points to potential for improvement in domestic recycling capabilities and public awareness.

10.4. Location

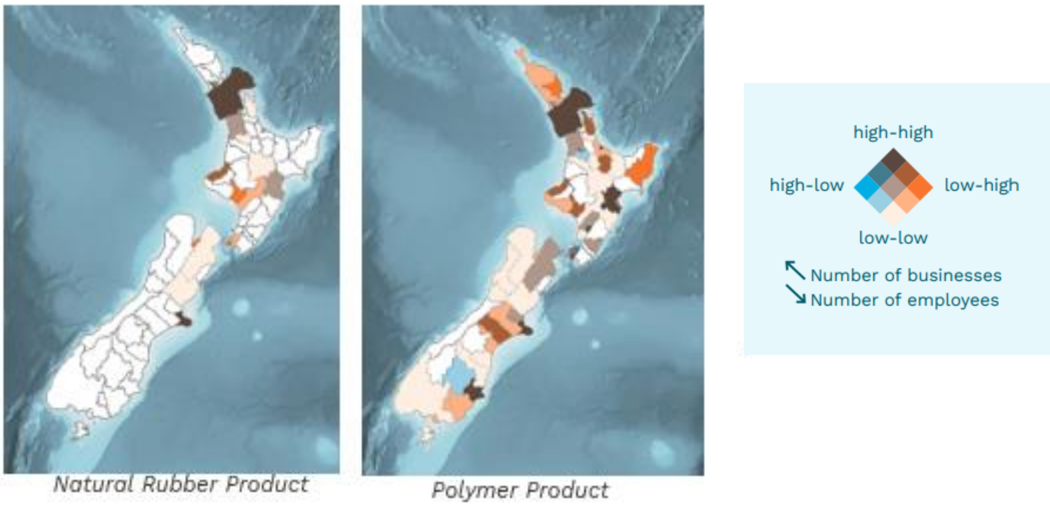

Figure 59 Manufacturing activity location – plastics and rubber ANZSIC Level 3 by territories, 2019

Polymer product and rubber product manufacturing activity is dominated by Auckland, followed by Christchurch, Hamilton City and Lower Hutt City. It is assumed the locations require constant and reliable energy sources for the heating components of the process.

10.5. Data gaps

There were several gaps identified as research progressed, including:

- Plastic litter data associated with plastic products manufactured or imported into NZ
- Links to chemicals and refining as raw material source, in particular resin impacts and imported product
- Links to food and beverage packaging
- Reuse models, in particular logistics and supply chain. Manufacturing supporting lease/return systems through repair and recycling. Examples include crates.
- Wash facilities incorporated into manufacturing e.g. Alto/Flight Plastics to process pre and post-consumer waste streams
- Publicly availably facility level waste information
- Durable products versus single-use manufacturing

10.6. Stakeholder perspectives

Workshop participants acknowledged valuable data on emissions and waste but pointed out gaps and a lack of granularity, especially regarding plastic types and the origins of carbon footprints from imported resins. The significant impact of scope 3 emissions, particularly from supply chains involving imported resins, underscored the need for more detailed data to understand sources and mitigation strategies better.

The discussion on waste data, emphasising the need to understand specific types of plastics and their waste quantities, was highlighted as crucial for informed recycling initiatives. The value of analysing customs import data to gain insights into the types and quantities of resins imported into New Zealand was noted, indicating its potential to help reduce associated carbon footprints.

Participants identified a need for more detailed information on the types and quantities of plastics imported and wasted, along with the carbon footprints of different waste management and recycling methods. Suggestions for obtaining this missing data included leveraging customs records and engaging with waste management companies for more accurate data, highlighting the potential of collaboration with research institutions and industry associations.

The discussion identified opportunities for increasing the use of recycled materials in manufacturing and exploring bio-based alternatives as crucial steps towards a sustainable and circular plastics and rubber sector. Developing more explicit guidelines and stewardship models for waste management and recycling was also emphasised, alongside the potential for implementing a rating system to inform consumers about plastic products' environmental impact and recyclability.

Sector-specific practices and challenges:

- **Waste and recycling management:** Participants shared their challenges and strategies in managing waste and recycling within the sector, noting the importance of certifications and partnerships with waste management companies. The focus on developing internal systems for tracking and managing waste and recycling points to an emerging infrastructure striving for efficiency and sustainability.
- **Emissions management:** The approach to managing scope 3 emissions, particularly in understanding and mitigating the carbon footprint associated with supply chains, indicates a sector-wide effort to address emissions comprehensively. The transition to sustainable electricity and efforts to make processes as low-carbon as possible were highlighted as key strategies.
- **Manufacturing processes and environmental impacts:** Insights into the sector's manufacturing processes, from raw material sourcing to end-of-life disposal or recycling, underscore a commitment to circular economy principles. The emphasis on recyclability, sustainable material sourcing, and using recycled plastics in new products reflects an integrated approach to reducing environmental impacts.
- **Collaboration and innovation for sustainability:** The importance of industry collaboration, highlighted through partnerships and joint ventures with waste management entities, underscores the sector's approach to advancing sustainability. The discussion on fostering collaboration and knowledge sharing

within the industry suggests a proactive stance towards achieving a zero-carbon circular sector.

10.7. Sub-sector conclusions

Although plastics and rubber manufacturing is a small proportion of NZ advanced manufacturing activity by GDP (4.6%), the sector has close links to other sectors, including resin inputs from the chemicals and refining sector, and providing plastic packaging for food and beverage manufacturing lines. Activity is largely based in the main centres of Auckland, Hamilton, Canterbury and Wellington. The sector faces external pressures from consumers and government to address plastic pollution.

Our top-down analysis showed minimal production-based emissions, indicating the domestic economy for plastic and rubber product manufacturing is very small. Imported products drive consumption-based emissions, with limited exports observed. This means there are challenges with decarbonising the sector as most of the emissions are associated with international supply chains. Of note, the production emissions of basic polymers in chemicals and refining are relatively high, contributing to supply chain emissions for polymer products. The exercise has also highlighted the limitations of this method at a more granular level, with future work required to attribute emissions to plastic and rubber proportionately. Auckland accounts for 50% of all emissions associated with plastics and rubber product manufacturing meaning there is opportunity to reduce emissions and waste output from this sub-sector by concentrating development of infrastructure and systems in Auckland.

Although the emissions intensity of this sub-sector is considered low in comparison to others, issues related to waste during product use and at end-of-life is critical to address and difficult to decouple from upstream stages of design and manufacturing. Potential waste streams associated with the manufacturing stage are related to direct inputs, personal protective equipment and packaging, but the product itself can be considered problematic. Internal circular loops have been identified, with further verification required.

Our 'bottom up' analysis focused on plastics and revealed the challenges of managing plastic waste and recycling. The significant reliance on imports, combined with the high volume of plastic ending up in landfills, suggests opportunities for improving recycling infrastructure and reducing plastic waste through policies and incentives. The relatively small amount of plastic being recycled also points to potential for improvement in domestic recycling capabilities and public awareness. The introduction of standardised kerbside collections in February 2024 is a good example of government-led interventions geared towards simplifying the plastics put onto the New Zealand market to phase out hard to recycle items and deliver high quality recycled materials with a higher resale value. This change is indicative of a changing flow of materials that may evolve rapidly to keep pace with New Zealand's domestic regulations and the regulations of our key trade partners.

Insights from stakeholders highlighted the importance of working closely with waste providers and the need to address scope 3 emissions within the supply chain. There was a strong commitment to circular practices and working collaboratively.

11. Other manufacturing

11.1. Sub-sector overview

Other manufacturing is the most diverse sub-sector within the advanced manufacturing space. We can split it into three broad categories: non-metallic mineral product manufacturing, textile, leather, clothing and footwear manufacturing, and furniture and other manufacturing:

- **Non-metallic mineral products** include cement and lime, plaster, bricks and ceramics, concrete products, and glass and glass products.
- **Textile, leather, clothing and footwear** manufacturing includes upstream material production activities such as wool scouring, leather tanning, and manufacturing textiles (natural and synthetic), as well as making products from them, such as carpets, ropes and twine, knitted products, clothing, or footwear.
- As well as furniture (wooden, upholstered, metal, or mattresses), the final **other manufacturing** category includes activities like jewellery production, toys, sporting goods and recreational products, and a final catch-all 'other manufacturing not elsewhere considered (n.e.c.)' category that includes everything from musical instruments to candles and paintbrushes.

Non-metallic minerals is the largest sub-sector on a financial basis, contributing almost as much to GDP as the other two groupings combined. Using real GDP figures (on a 2010 baseline) from the 2018 MBIE manufacturing sector report, these were $1.2 billion, $600 million and $700 million for each sub-sector respectively (MBIE, 2018). Exports for 2017 totalled $1.3 billion, mainly leather, textiles and clothing, and wool, along with a smaller 'miscellaneous' category.

The non-metallic minerals sector is dominated by a small number of large players, with Golden Bay Cement (owned by Fletcher Building) being the only producer of domestic Portland cement, Graymont Lime being the largest quicklime and slaked lime producer, and Visy glass being the major glass manufacturer. Production emissions are concentrated at the materials manufacturing stage, with intensities decreasing further down the value chain. This is where the company variety starts to increase as well, with different producers of concrete products (including ready-mix and precast elements), and glass fabrication firms. Flat glass is entirely imported into NZ, as is around two thirds of the cement used domestically. This sub-sector exports very little compared to others in the manufacturing sector, with production focused on the domestic market.

Primary production is highly concentrated across a few large sites, with Golden Bay Cement being located in Whangarei, Graymont Lime having kilns across Waikato and in Otago, and Visy glass has its large factory in Auckland. Downstream suppliers are much more distributed, with overall employment concentrated in Auckland (MBIE, 2018).

2020 and the global pandemic highlighted the brittleness of international supply chains for Aotearoa New Zealand's textile industry. The textile industry is a predominantly linear system and is under scrutiny for over-production and over-disposal of textile waste. Opportunities for unwanted textiles to be sent to charity or shipped overseas are becoming more difficult due to over-supply and import restrictions, as well as the ability and capacity for repair and repurpose (Casey & Johnston, 2020). This sector deep-dive identified 175,000 tonnes of textile waste went to landfill in Aotearoa New Zealand in 2019.

The furniture market in NZ has been increasingly dominated by imported goods over the last decades, with the local industry moving away from the mass market to higher-margin, higher-priced products (Taylor, 2015; Danske Møbler, 2023; Figure NZ, 2023). It has not formed a significant part of this assessment.

11.2. Top-down assessment

11.2.1. Greenhouse gas emissions

This sector includes a collection of various sub-sectors with vastly different emissions profiles. Analysis is provided for three subsets of the data: textiles, non-metallic mineral products, and furniture/other manufacturing.

The first main sub-sector grouping of textiles, leather, knitted products, and clothing, has comparatively low emissions on a production and consumption basis.

These production sectors are not large domestically and seem mostly import-driven. These sub-sectors are also less emissions-intensive compared to sub-sectors like meat and dairy products, so the overall footprint is low. The low domestic participation in this sub-sector may be a result of a competitive global market, and a struggle to remain price-competitive with large producers of textiles and clothing products like China, Vietnam, India or Bangladesh. Even when considering the imports of these goods, the consumption-based footprint is relatively small compared to other sub-sectors. Circular opportunities from a waste perspective may be more relevant to investigate from an NZ-specific perspective.

Non-metallic minerals, especially cement, lime, and concrete product manufacturing, is the largest sub-sector classed under other manufacturing. In contrast to the first sub-sector grouping, this has a large domestic component, shown by the smaller gap between production and consumption-based emissions. The negligible difference between consumption emissions with and without exports indicates that very little of NZ's domestic production is exported overseas, and that it is significant for local downstream industries such as construction and infrastructure development.

Other manufacturing is a sub-sector including a collection of miscellaneous products not covered by the main ANZSIC06 categories. There is a mix of domestic production and imports here, but further analysis is difficult considering the wide range of products covered in this category.

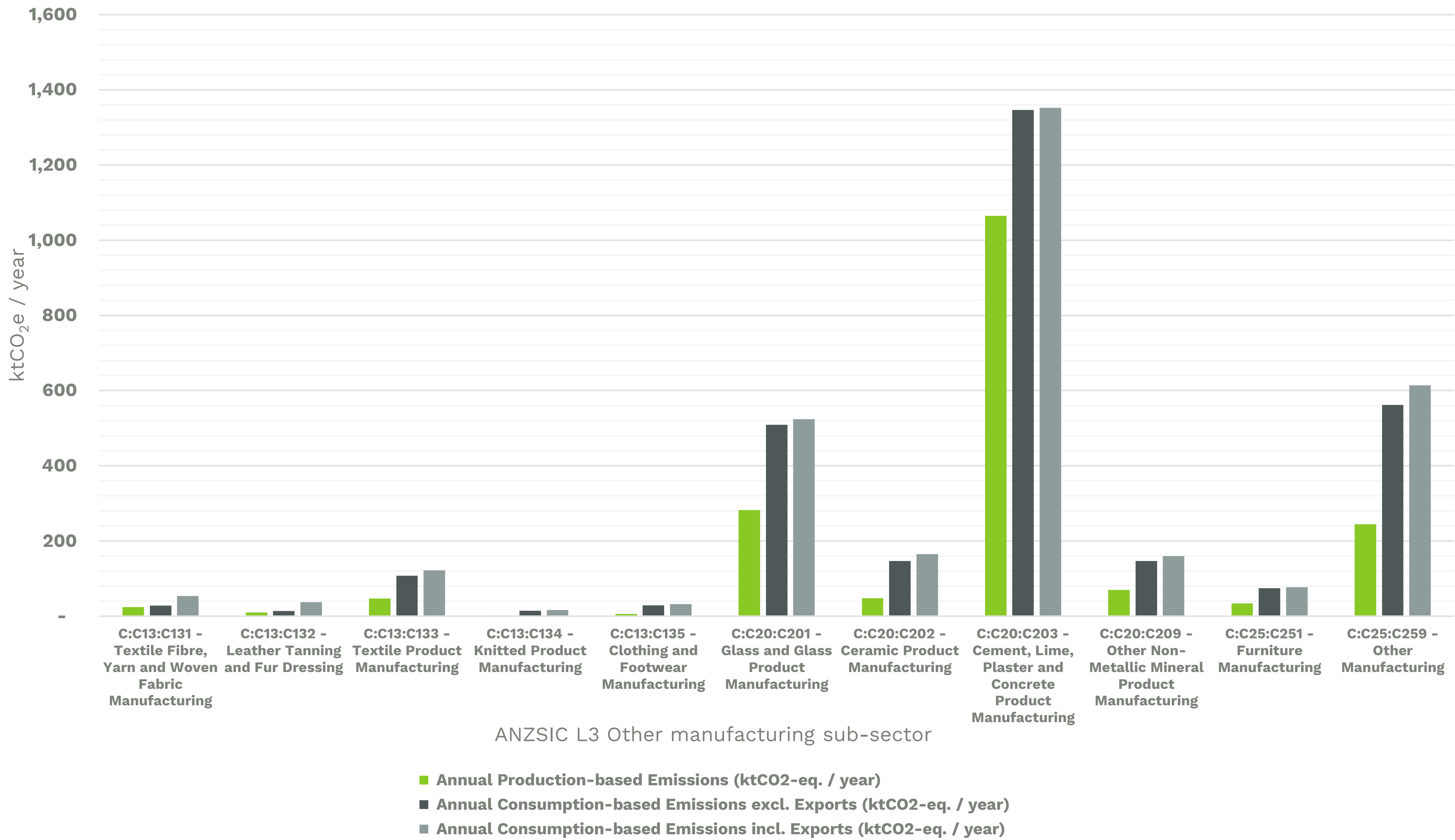

Figure 60 Annual production- and consumption-based emissions from the other manufacturing sub-sectors ($ktCO_2e$ / year), 2019 baseline

Due to one-to-many mappings in the data, all the non-metallic mineral products are allocated the same emissions intensities. When we then look at the emissions totals, and see cement, lime, and concrete products accounting for a larger chunk of emissions than the others – this indicates a larger spend in the economy for these products, and an associated large revenue stream for those manufacturers. These products are a core input to the construction sector so it is unsurprising to see it dominate this sub-sector.

Cement and lime production are considered 'hard-to-abate' sectors, and with offshore production being more challenging to influence, reducing emissions in these supply chains is difficult. NZ's centralised production of these materials (one cement production plant, and one major lime producer across multiple plants) may ease the transition to lower-emissions technologies once they become available, but limited capital availability might hinder these efforts.

In the meantime, the use of alternative products can be ramped up in these markets, especially for cement. Waste products such as imported blast furnace slag from steel production and fly ash (both imported and from the Huntly coal-fired generation plant) are increasingly being used to replace Portland cement in concrete, and locally sourced natural pozzolans such as volcanic ash may be promising alternatives in the near term. We note that demand for these waste products is increasing internationally. However their supply is likely to decrease over time as global coal usage declines and steel demand stagnates, highlighting the importance of local supplies of alternatives. These efforts link naturally with the development of the circular economy across the non-metallic mineral sub-sector, utilising wastes from other sectors.

Similar to other sub-sectors, Auckland has the largest share of the emissions. As with the previous section on machinery and equipment, there is a significant drop-off after the first region, with Auckland alone accounting for approximately 40% of the national total. It is difficult to provide further analysis for other manufacturing due to the range of products, and further disaggregation to ANZSIC Level 3 would provide more useful commentary. Interestingly Auckland is the dominant source across all these different sub-sectors and example products – which is likely due to the employment and business numbers used for regionalisation, rather than the raw emissions data itself.

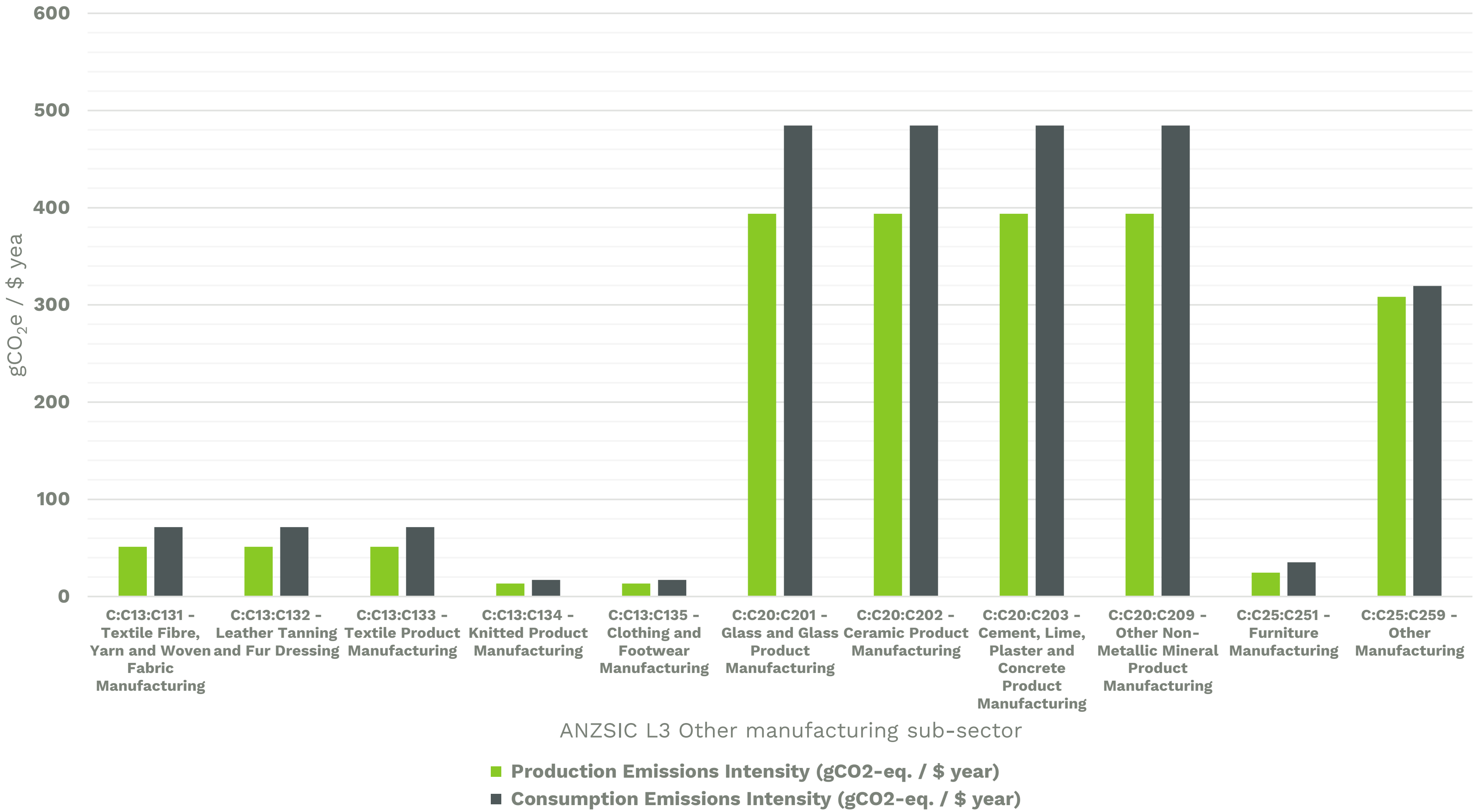

Figure 61 Production- and consumption-based emissions intensities for the other manufacturing sub-sectors (gCO₂e / dollar - year), 2019 baseline

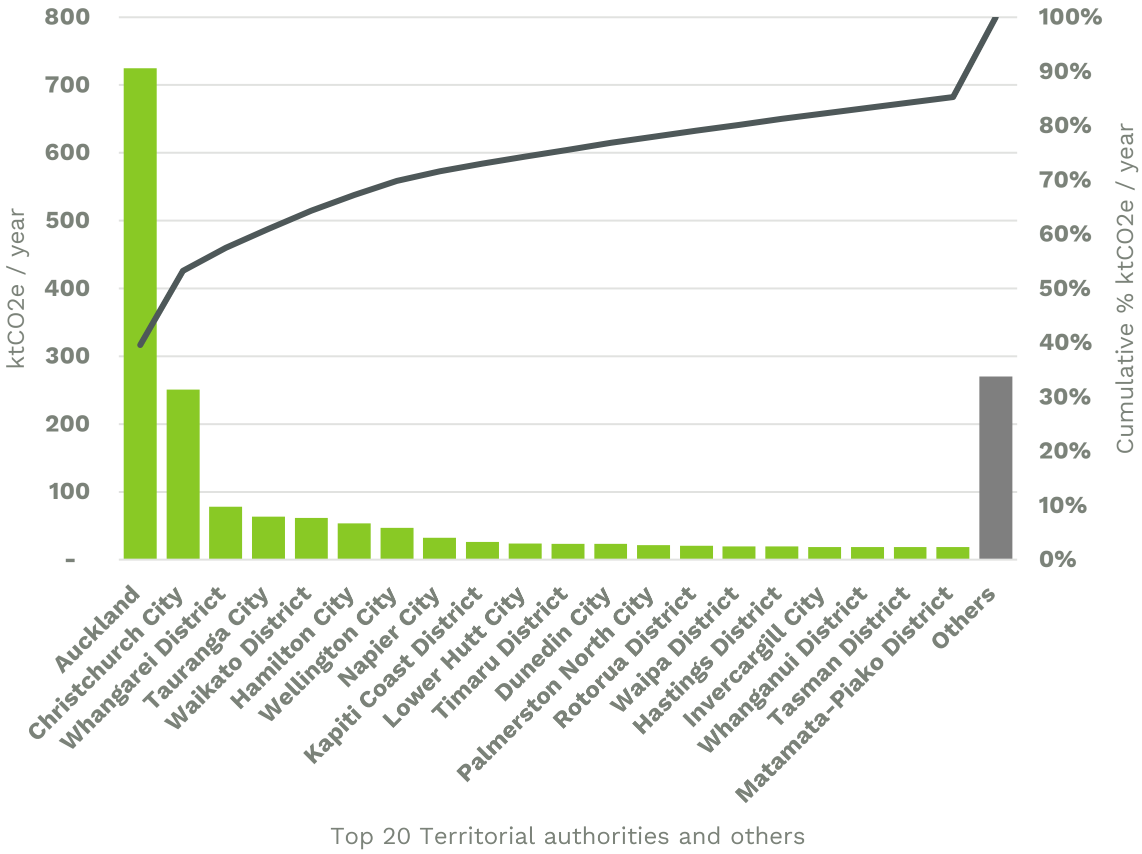

Figure 62 Annual production-based emissions of the other manufacturing sub-sectors across NZ territorial authorities (ktCO_2e / year), 2019 baseline

Overall, other manufacturing is a varied sector with a range of example products. The non-metallic minerals manufacturing sub-sectors are the largest emitters when considering emissions intensity, overall production emissions, and consumption-based emissions. Of these, cement, lime, and concrete products are the most significant source, which is also a function of the large requirement for these goods throughout the construction industry in NZ. Auckland once again is the largest contributor to the national total, across all sub-sectors of other manufacturing, and further analysis should be undertaken to look at sub-sectors individually rather than as a grouped sector.

11.2.2. Waste

Focusing on potential other manufacturing waste generation, the following associated streams are outlined in Table 11.

Table 11 Other manufacturing waste characterisation by waste material composition, SWAP categories

	Other manufacturing	Identified source examples
Organics	✓	Scouring/retting vegetable matter
Cardboard and paper	✓	Packaging
Timber	✓	Offcuts, packaging
Rubble/Concrete incl cleanfill	✓	Defective materials
Potentially hazardous	✓	Waste chemicals, dye/tanning liquor, scouring sludge, oils and lubricants, kiln dust, contaminated rags and wipes, resins
Plastic	✓	Defective parts, offcuts, foam, packaging, packaging
Metals	✓	Defective and corroded parts, offcuts
Textiles	✓	Defective product, samples, offcuts, personal protective equipment
Nappies and sanitary	✓	Personal protective equipment
Glass	✓	Defective parts, offcuts, fibreglass
Rubber (incl tyres)	✓	Defective product, offcuts

Through qualitative resource flow scan activities, we identified potential waste outputs associated with production. Other manufacturing includes a wide range of different products including textiles, cement and concrete, mattresses and furniture, glass, ceramics, brick manufacturing and jewellery. There is also a catchall 'other' which remains ambiguous. This means it is difficult to exclude any key waste material streams due to the significant variance in input materials, processes, and outputs. As such, ‘potentially hazardous’ waste is also expected to be diverse with particular challenges including waste chemical and dust outputs associated with processing and fabrication.

11.3. Bottom-up assessment

11.3.1. Qualitative resource flows

Part of the resource and waste mapping for the other manufacturing included the development of material flow diagrams at ANZSIC Level 4. These identify the key product, input resources, and output co-products, by-products, and waste products. This work also identified opportunities for circular resource flows across ANZSIC Level 3 and 4. Sub-sector material flow diagrams completed to date include:

- A combination of C2021 Clay Brick and C2031 Cement + Lime (Figure 63)

- C1351 Clothing (Figure 64)

These flow diagrams are shown on the following pages. Overall, this exercise has identified some key findings and opportunities. As a varied sector with a range of example products, processes and typical resource flows vary between ANSIC Level 4 classifications. Patterns emerge when grouping: textiles, leather, knitted products, and clothing; and non-metallic minerals.

Textiles, leather, knitted products, and clothing

- Natural wool and fibres can be composted in special conditions, dependent on the presence of chemical additives (Angelo, 2020)
- End-of-life wool, and offcuts, are produced into insulation, blankets, and other second-generation wool products (Casey, Crowe, Pretorius, & Thompson, 2022)
- Sludge possibly can be composted, depending on contamination risk, in cement-based construction materials (Jian, Li, Xing, & Sun, 2020)
- Although carpets are not accepted in kerbside recycling (MfE, 2024), there are opportunities to reuse carpet within the sub-sector e.g. take-back schemes recycle wool carpet for underlay for new carpet installations (AGM, 2012); or ReEntry product stewardship programmes that recycle synthetic carpets into new products (Sands, 2021)
- Natural textiles can be recycled fibre-to-fibre after a garment has been made and returned. Waste is sent to Europe to be recycled in a fibre-to-fibre chemical recycling process. Old cotton is shredded, turned into a slurry, made into a pulp and then fed back into the textile production chain. This fabric is then used again to make new clothing (Little Yellow Bird, 2023)
- Raw PET is being extracted from polyester uniforms and used for new plastic products at pilot scale. The business case is not feasible due to lack of viable volumes, cost, and early stages of fibre-to-fibre technology (Casey, Crowe, Pretorius, & Thompson, 2022)
- Cellulose is being extruded from cotton fibre for use as an additive in roadmixes (Casey, Crowe, Pretorius, & Thompson, 2022)
- Discarded textiles (including at end of life), ideally 100% composition, are currently able to be recycled into a range of textile products, e.g. geotextiles, wadding, felted protective blankets, ped beds, home insulation and carpet underlays (Textile Products, 2021)
- Product care and repair schemes exist to maintain value and extend the life of textile products (Patagonia, 2022; Kowtow, 2024)

Non-metallic minerals

- Fly ash, and pond ash (or bottom ash), by-products from Huntly Power Station, are being used as an alternative supplementary cementitious material (SCM) by Fletcher Building in partnership with Genesis (Sarney, 2023)
- There are examples of transfer stations performing concrete recycling, by crushing the waste and using it as aggregate (Auckland Council, 2024)
- Demolition and construction waste such as cements, concretes and gravels can be collected commercially and turned into cleanfill (Waste Management NZ, 2021)

- Demolished concrete can be returned to manufacturers to have the steel removed so it can be utilised in recycled concrete products, e.g. base course, and drainage aggregate. Surplus concrete can be used for blocks or be processed into hardfill. Waste material from this processes is used on farms as fertiliser substitutes (Atlas Concrete, 2020)
- Many products in this category (e.g. bricks and cement) can process waste heat recovery to reuse heat in plant processes (MBIE, 2019)
- To reduce waste water, process water can be stored, process, and recirculated (Proflow, 2024)
- End-of-life glass is being recycled into terrazzo construction products (Giacon Terrazzo, 2024)

Other manufacturing

- ReBound product stewardship programme takes back mattresses for recycling of materials, e.g. steel springs (100% recyclable), wood (100% recyclable), polyurethane foam (recycled for carpets), coir (numerous reuse options) and textiles (currently non-recyclable) (Speirs, 2018)
- Sourcing recycled materials through recycled content providers or give-back schemes is common in the jewellery industry, e.g. upcycled glass or recycled sterling silver and copper (Stone Arrow, 2024); sourcing upcycled beads for community therapeutic workshops through give-back schemes (Sustainability Trust, 2024); or gold, brass, and silver customer give-back schemes incentivised with store credit (Luna & Rose, 2024; NBA News, 2024)

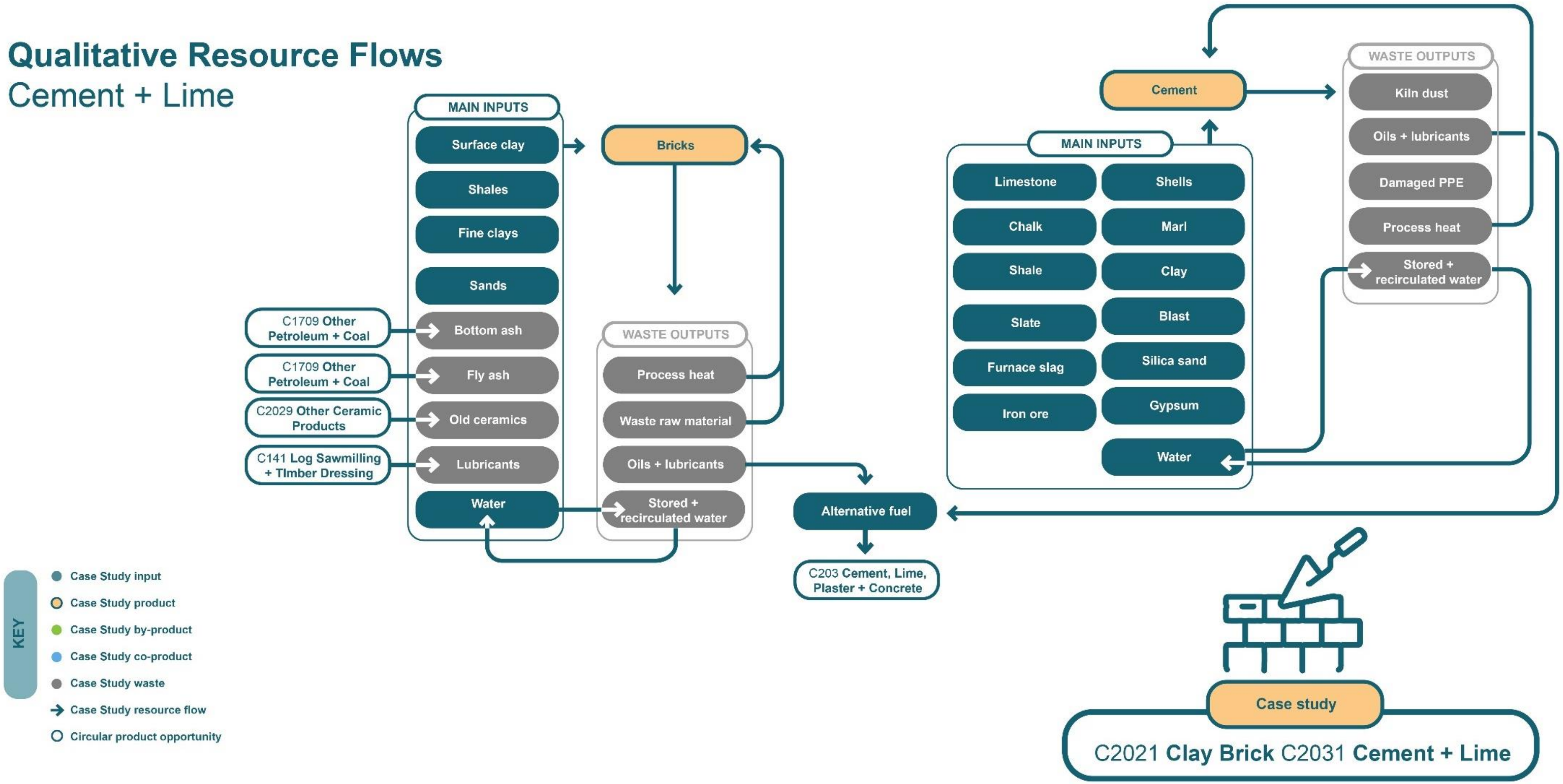

Figure 63 Resource flow map for Cement and Lime (C2031) and Brick (C2021)

Qualitative Resource Flows
C1351: Clothing

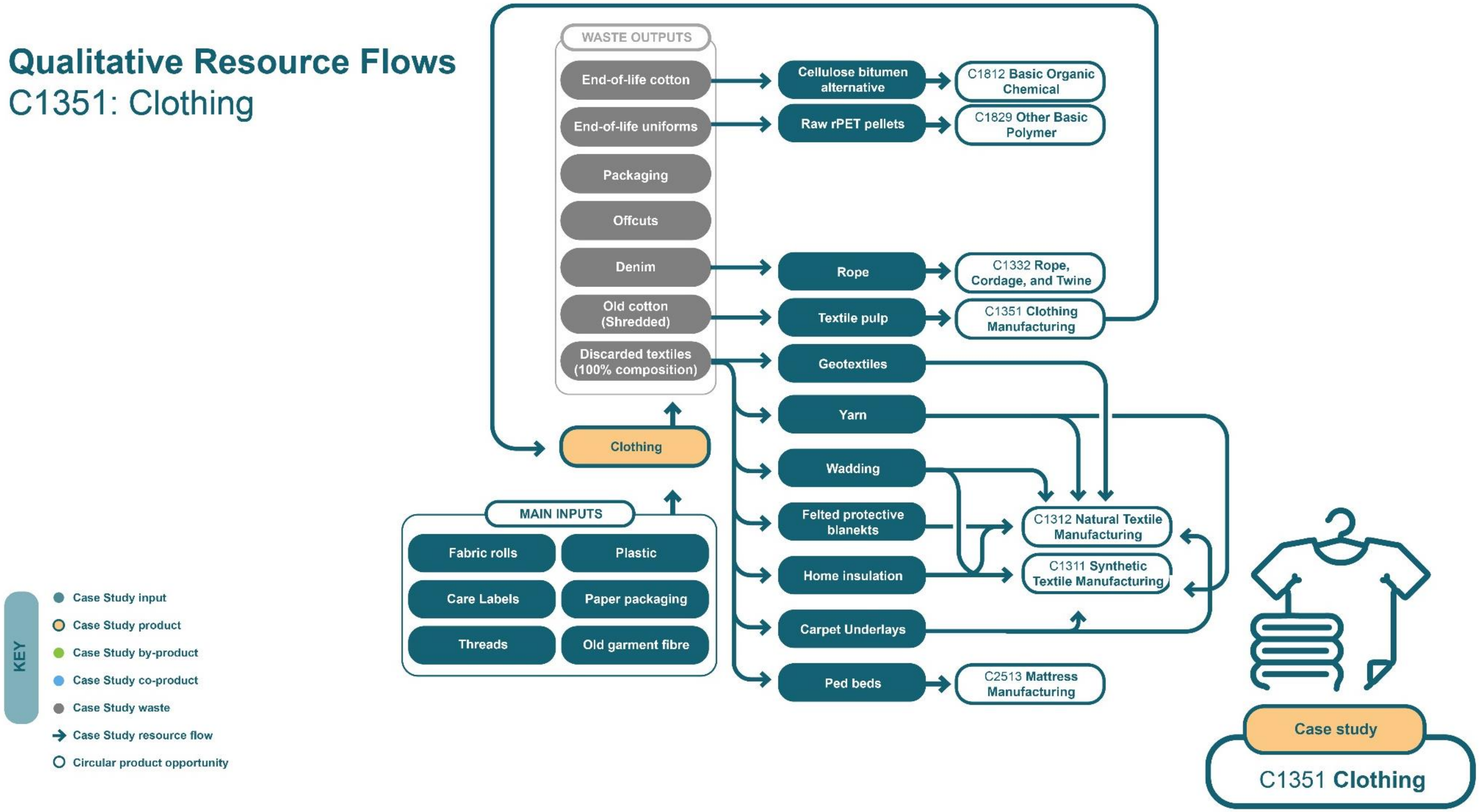

Figure 64 Resource flow map for Clothing (C1351)

11.3.2. Key material flows

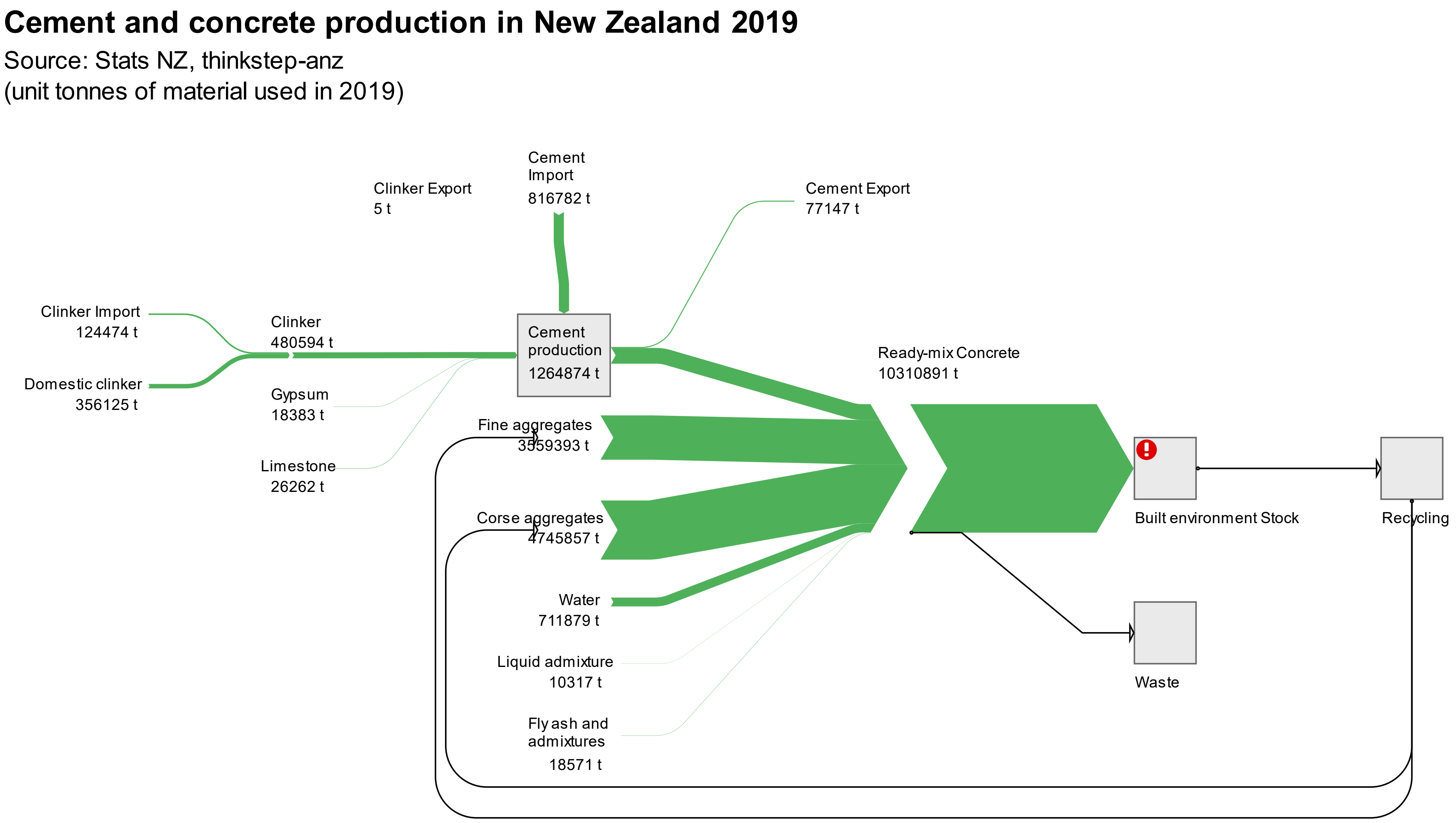

Figure 65 Cement and concrete production flows in New Zealand (2019)

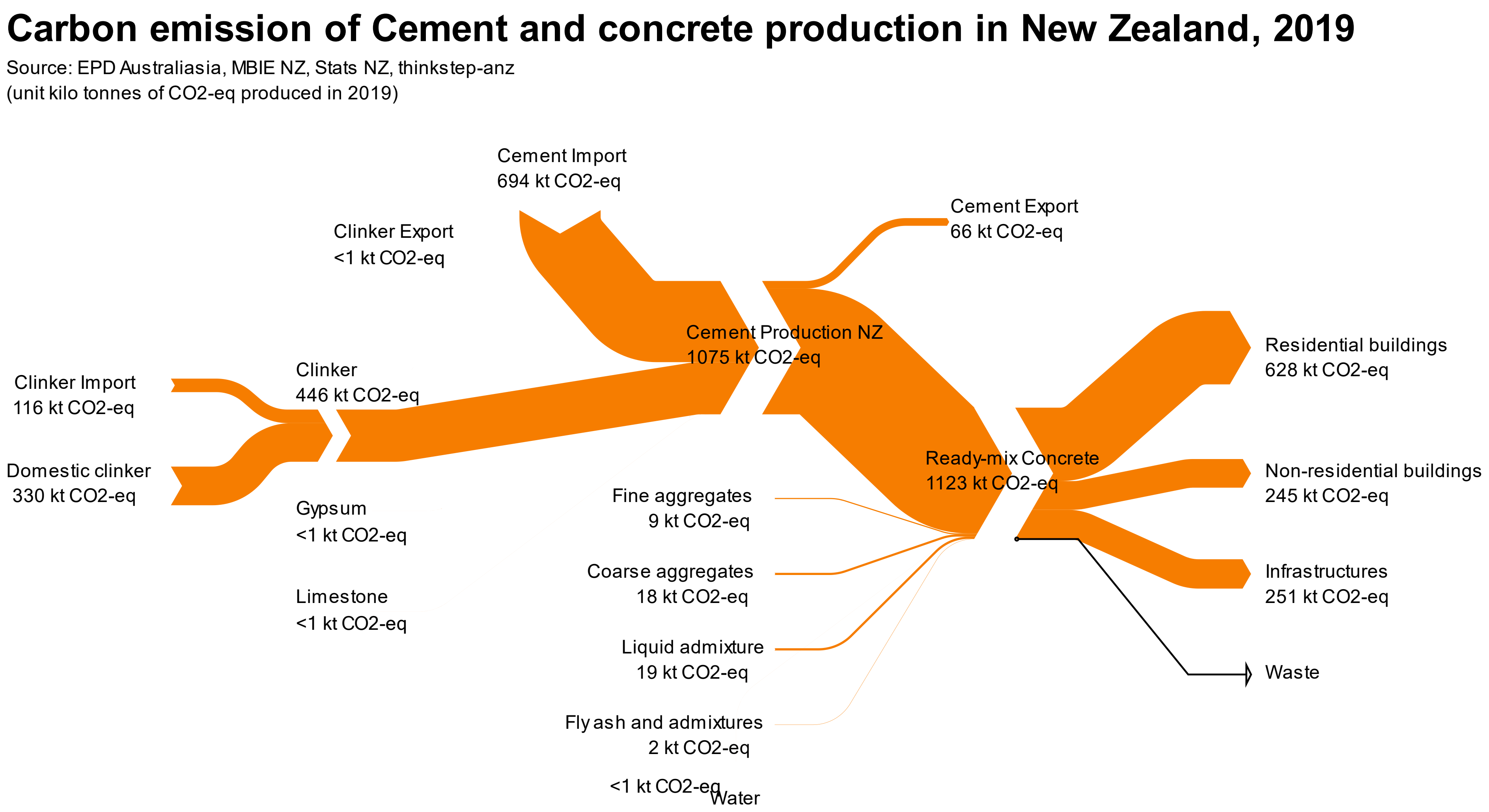

Figure 66 Cement and concrete emissions in New Zealand (2019)

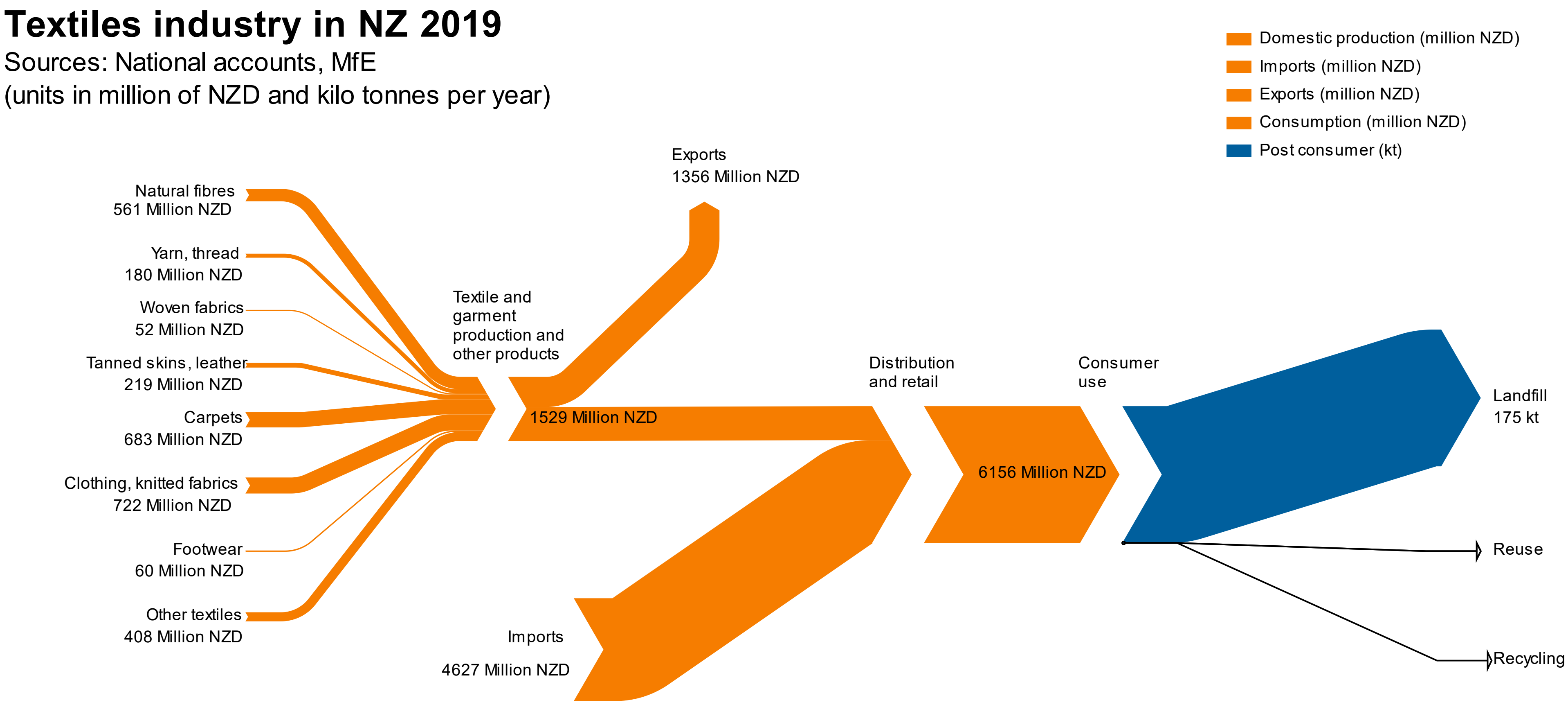

Figure 67 Textile industry economic flows in New Zealand (2019)

11.3.3. Hotspots identified

With reference to Figure 65 and Figure 66, the two Sankey diagrams provide a comprehensive view of New Zealand's cement and concrete production in 2019 by showing both the mass flows in tonnes and the associated carbon emissions.

In the mass flow diagram, we observed that the domestic production of clinker, a key component of cement, is significant, totalling 356 kt. This is complemented by imports of 124 kt, demonstrating reliance on both domestic production and foreign sources. The mass of cement produced domestically stands at 1,264 kt, which then contributes to the production of a substantial amount of ready-mix concrete, totalling 10,310 kt. Other constituents include 4,746 kt of coarse aggregates, 3,559 kt of fine aggregates and 712 kt of water, 19 kt of fly ash and admixtures and 10 kt of liquid admixtures. The resulting concrete is used within the built environment, contributing to infrastructure, residential and non-residential buildings. The flows of materials such as gypsum (18 kt), and limestone (26 kt) highlight a diverse range of raw materials involved in the production process.

In contrast, the carbon emissions diagram offers a perspective on the environmental impact of this industry. Notably, the import of cement is a major contributor to emissions, with 694 kt CO_2e. The domestic production of clinker accounts for 330 kt CO_2e and imported clinker an additional 116 kt CO_2e. Cement production accounts for 1,075 kt CO_2e of the 1,123 kt CO_2e emissions of the ready-mix concrete produced – i.e. 96%. These emissions are ultimately allocated to different sectors, with residential buildings being the largest identified final contributor (628 kt CO_2e), followed by infrastructure (251 kt CO_2e) and non-residential buildings (245 kt CO_2e).

The comparison between the two diagrams underscores the environmental impact of cement and the relevance of the New Zealand net-zero carbon concrete industry roadmap's focus on Supplementary Cementitious Materials (SCMs). While the mass flow diagram illustrates the physical quantities of materials used and products created, the emissions diagram indicates that the production and use of cement have a significant carbon footprint, especially when the end use is considered. This suggests the need for strategies to reduce emissions at all stages, from material production to end-use. For instance, reducing the import of high-emission cement, increasing the efficiency of domestic production processes, and enhancing the recycling of concrete could be key areas for potential environmental improvements.

Furthermore, the export and import figures for both clinker and cement suggest that while New Zealand exports some of its production, it relies heavily on imports to meet its demand. This has implications for the country's trade balance and carbon accounting, as imported materials contribute significantly to the sector's carbon footprint.

Textiles

Figure 67 maps out the economic and material flows within the textiles industry in New Zealand for the year 2019, detailing the monetary values in New Zealand Dollars (NZD) and the post-consumer waste in kilotonnes (kt). Key points from the diagram are:

1. **Domestic production and import dependency:** The diagram shows that domestic production of textiles contributes $2,885 million to the economy, $1,356 million of which is exported and $1,529 million is consumed domestically. However, this is significantly outstripped by imports, which are valued at $4,627 million, indicating a high reliance on imported textiles. This could reflect a combination of consumer preference for foreign textiles, cost-effectiveness of importing versus domestic production, or a gap in domestic production capacity.
2. **Exports:** Despite the high level of imports, New Zealand's textile industry also contributes to the global market, with exports totalling $1,356 million. This suggests that while the domestic market relies on imports, New Zealand's textile products are also competitive internationally.
3. **Consumer spending:** Consumer spending on textiles is substantial, with consumption valued at $6,156 million, which is the largest monetary flow in the diagram. This indicates a strong domestic market for textile products.
4. **Post-consumer waste:** At the post-consumer stage, 175 kt of textiles end up in landfill, which is indicative of waste management challenges within the textiles industry. The diagram indicates that data for reuse and recycling of textiles domestically is missing, pointing to potential areas for improving data and transparency on textiles.
5. **Breakdown of domestic production:** The diagram breaks down domestic production into various categories, including natural fibres, yarn and thread, woven fabrics, tanned skins and leather, carpets, clothing from knitted fabrics, footwear, and other textiles. Carpets and knitted fabric clothing represent significant portions of the domestic production value, at $683 million and $722 million, respectively.

The data suggest opportunities for enhancing sustainability through increased recycling and reuse, potentially reducing landfill waste. Furthermore, the significant discrepancy between imports and exports could prompt considerations of how to bolster domestic production or diversify the textile market within New Zealand.

11.4. Location

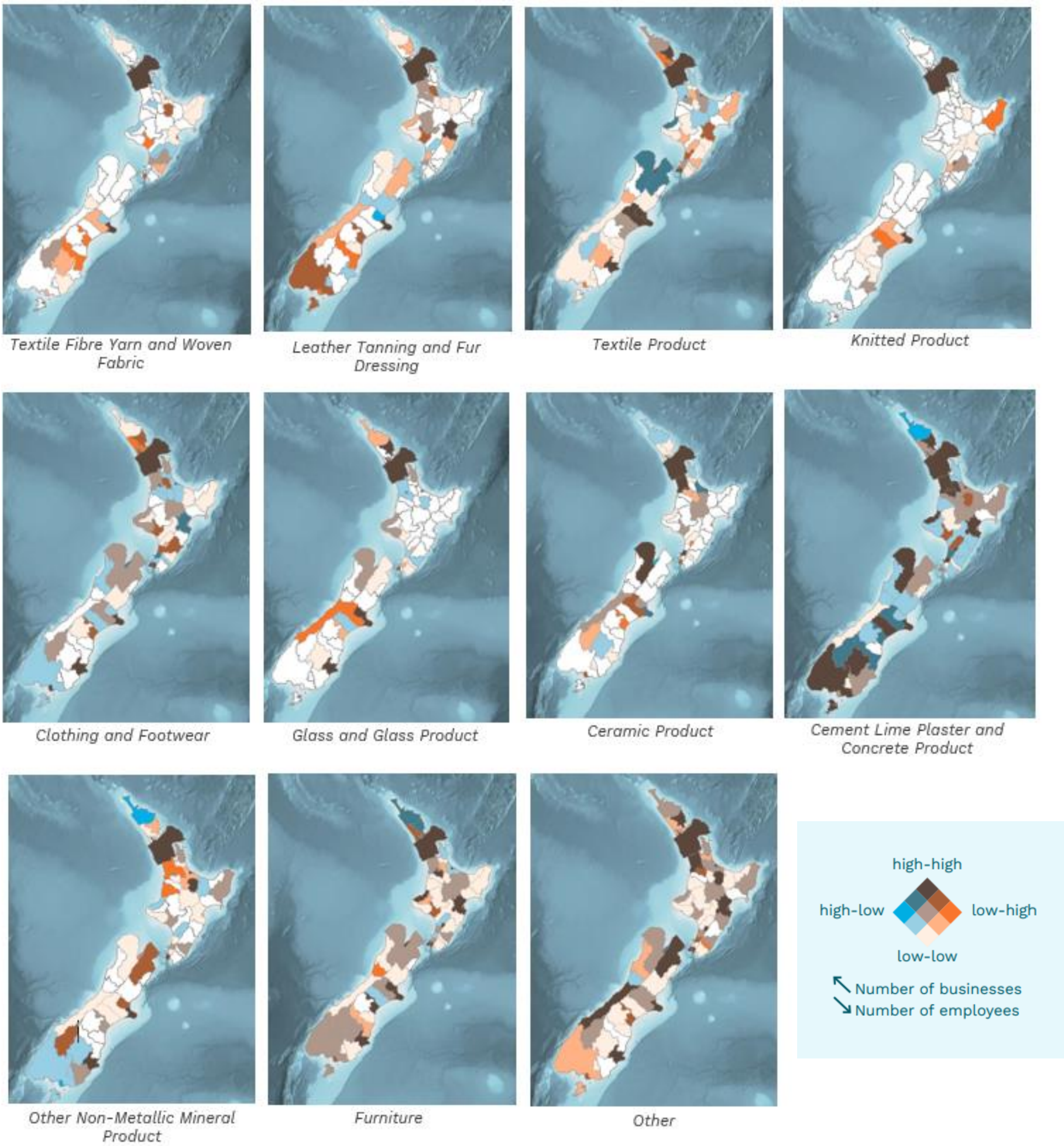

Figure 68 Manufacturing activity location –other manufacturing ANZSIC Level 3 by territories, 2019

Textile, leather, clothing and footwear manufacturing activity is seen to be heavily anchored in Auckland followed by Christchurch City then Tauranga City. Non-metallic mineral product manufacturing activity is also found mostly in Auckland, Christchurch City followed by Tauranga City. Furniture and other manufacturing activity operates mostly in Auckland and Christchurch followed by Wellington City.

11.5. Data gaps

Identified gaps included stocks associated with 'other manufacturing'. We anticipate this may have strong relevance to the construction industry asset base and construction and demolition waste.

Another area identified was textile emission intensities by fibre type. This is difficult to assess based on current available data and imported emission gaps and potential focus areas for further investigation include glass manufacturing and mattress production. We also note challenges with a long 'tail' (i.e. many small-scale activities), with further work needed to understand manufacturing outliers that are not represented in the other ANZSIC codes.

11.6. Stakeholder perspectives

Participants at the workshop expressed that while some insights were anticipated, such as emissions data from sectors like cement, lime, and textiles, challenges in translating financial data into physical quantities were evident. The complexity and variability of data sources hindered a comprehensive understanding of material flows and emissions, revealing a gap between expectations and the reality of data accessibility and utility.

Emissions data, particularly for cement and concrete, was notably interesting, shedding light on the significant impact of certain materials on emissions. The data emphasised the necessity of considering the entire supply chain and highlighted opportunities for identifying circular economy initiatives. The qualitative mappings offered detailed insights into specific sectors, establishing a basis for further exploration of sustainability opportunities.

A notable absence of detailed information on products' end-of-life phases was identified, particularly in recycling and re-manufacturing processes. The need for improved data on hazardous waste from various manufacturing processes and to capture information on second-hand markets and repair initiatives was also highlighted. Suggestions for acquiring missing data included engagement with industry associations, leveraging government and council data, and exploring new data collection methods, such as standardised reporting frameworks or technology-based solutions like GIS and remote sensing.

Discussions unveiled opportunities for increasing recycling and re-manufacturing of materials, particularly textiles and composites. There was a strong emphasis on the potential for product-as-a-service models and the importance of designing for durability and reparability to extend product lifecycles and minimise waste.

Sector-specific practices and challenges:

- **Waste and recycling management:** Challenges in obtaining accurate waste data due to non-standardised measurement units were discussed, highlighting the industry's spectrum of waste management practices and the role of Industry 4.0 technologies in enhancing operational efficiency and waste minimisation.
- **Emissions management:** The sector's approaches to managing and reporting emissions, particularly scope 3 emissions, emphasise supply chain engagement and the selection of suppliers aligned with sustainability goals. The need for

better data sharing and industry collaboration to support sustainability goals effectively was underscored.

- **Manufacturing processes and environmental impacts:** Insights into the sector's manufacturing processes, from raw material sourcing to end-of-life disposal, underscored the importance of sustainable practices, including recycling, re-manufacturing, and integrating renewable energy sources to improve operational efficiency and reduce environmental impact.
- **Collaboration and innovation for sustainability:** The potential for cross-sector collaboration and adopting standardised reporting frameworks and innovative technologies was highlighted as crucial for advancing circular economy goals. The discussions emphasised the importance of government support and industry-wide efforts towards sustainability.

11.7. Examples and case studies

The following case studies identify specific examples of circular practices in NZ currently:

11.7.1. Case study: Inzide and Interface's ReEntry product stewardship programme

Introduced to NZ in 2009, this product stewardship scheme sends containers of end-of-life Interface carpet tiles exported back to their mill to be made into new carpet tiles.

11.7.2. Case study: Cavalier Bremworth and Textile Product's 'Flashbac' product

End-of-life wool carpets could be deposited in four dedicated carpet recycling containers at Envirowaste transfer stations at reduced cost. The waste wool is then recycled to become carpet backing that replaces imported virgin jute.

11.7.3. Case study: StrengthTex by UsedFULLY

Focusing on textiles as a resource, not as a product. Due to limited onshore processing capability, UsedFULLY ran a successful pilot of StrengthTex – a cellulose bitumen-alternative derived from waste cotton textiles. This product was laid in April 2022 on roads in Te-Whanganui-a-Tara Wellington.

11.7.4. Case study: Atlas Concrete concrete recycling

Atlas Concrete repurpose numerous forms of concrete waste. Demolished concrete is processed into four different grades of aggregate and drainage. Surplus concrete is processed into blocks or hardfill. Any waste material from processing is then delivered to farms to be used as a fertiliser alternative.

11.7.5. Case study: ReBound product stewardship programme

With an estimated 300,000 mattresses entering landfill a year in Aotearoa New Zealand, this proof-of-concept product stewardship programme predicted a potential 90%

diversion rate following a successful trial. By recycling the steel springs, wood, polyurethane foam, and coir, similar programs could divert 2 million kgs of metal and 3 million kgs of foam, timber, and coir from landfill.

11.7.6. Case study: Golden Giveback and Re:cycle product stewardship programme

Luna & Rose and Michael Hill jewellery manufacturers have introduced product stewardship programmes that incentivise customers to return old gold, sterling silver, copper, and brass to their stores by offering store credit.

11.7.7. Case study: R.O.S.E product stewardship programme

Reusing Oil Saves the Environment (ROSE) product stewardship programme recovers and reuses used oil nationwide. A collaboration between Fulton Hogan, Salters Cartage, and Petroleum Services, it provides used oil as an alternative fuel source to contracted and consented businesses.

11.7.8. Case study: Fletcher Building Supplementary Cementitious Material

Fly ash, and pond ash (or bottom ash), by-products from Huntly Power Station, are being used as an alternative supplementary cementitious material (SCM) by Fletcher Building in partnership with Genesis.

11.8. Sub-sector conclusions

Other manufacturing is a diverse category that includes non-metallic mineral products, textiles, leather and footwear, furniture, jewellery, toys, sporting goods, recreational products, musical instruments, candles, paintbrushes, etc. The non-metallic minerals component represents the most significant flow within the sub-sector, contributing $1.2 billion to New Zealand GDP, with textiles contributing a further $600 million. Non-metallic minerals are dominated by a few large businesses including Golden Bay Cement, Graymont Lime and Visy glass. A larger number of concrete and glass product manufacturers sit downstream of these within the New Zealand market.

Our top-down assessment indicated that primary production accounts for much of the emissions footprint of non-metallic minerals and that all flat glass and two-thirds of the cement we use are imported. New Zealand's production of non-metallic minerals is highly focused on the domestic market, with low exports. Geographically the impacts from non-metallic minerals and textiles tend to follow the areas with the highest populations.

Cement and lime production are challenging to decarbonise and are core to domestic infrastructure development. New Zealand's high import dependence indicated a limited opportunity to influence the carbon footprint of the cement and lime we use. Conversely, the centralised nature of the domestic production of these materials seemed to suggest that lower-emission technologies may be more easily implemented as they become available. The use of alternative and supplementary cementitious materials (SCM) for concrete in New Zealand forms an integral part of the industry zero-emission roadmap. Interestingly, although the slags commonly used in SCMs are derived from steel production, the process used at NZ Glenbrook does not produce slag suitable for this. Along with the phase-out of coal power at Huntly reducing local supplies of flyash, SCMs will be increasingly sourced internationally. Alternative options such as natural pozzolans from volcanic ash may soon provide local alternatives.

Waste data indicates a significant flow of rubble into landfills within New Zealand. The use of these materials as recycled aggregate seems promising, but it needs to be considered in light of potential contamination from carbonated and chloride-contaminated cement, which may reduce the lifespan of reinforcing steel if used inappropriately. Large players in the construction industry, like Fulton Hogan and Fletcher Building, are actively utilising other sub-sectors' waste products for their own processing and production. The development of regulated, commercial recycling and product stewardship programmes supports businesses in supplying their waste products for repurpose.

Our bottom-up assessment of non-metallic minerals highlighted that despite a significant consumption of clinker for use in concrete, the emissions caused by cement production remained the most significant, with ready-mix concrete contributing 1,123 kt CO_2e in 2019, roughly half of which was associated with residential buildings and the rest split evenly between non-residential buildings and infrastructure. The substantial flow of these minerals into stocks raises the question of how long they will remain in service and when they are likely to become waste. This has been highlighted as a key data gap required to model the life-cycle of this class of material more accurately.

Our bottom-up assessment of textiles also indicated consumer spending of $6,156 million in 2019 with a heavy reliance on imports, with $4,627 million of imported goods versus $1,529 million of domestically produced goods consumed by the New Zealand economy. The $1,356 million of exported textiles points to a strong export market and the potential capacity for New Zealand to service more of its own supply needs. Waste data for textiles indicated 365 kt of textiles being sent to Class 1 or 2 landfills in 2019. We believe this is the majority of end-of-life textiles but lacked the data to convert the value of the diverse textiles put onto the market into the mass of textiles sold.

Despite the variation of products and processes in the ANZSIC level 4 industries in this sub-sector, other manufacturing is actively delivering product stewardship programmes at pilot and commercial scales. Our stakeholder engagement indicated a close focus on supply chain engagement, sustainability and sustainable procurement.

We observed that a lack of onshore processing capability may be limiting the application of new technologies, such as fibre-to-fibre processing, in the New Zealand market and causing circular systems to rely on exporting products for repurposing. Industry-led working groups are driving change in industries but require government investment and support to apply innovation at a commercial scale.

12. Additional associated research

Advanced manufacturing as a whole was one of the sectors focused on by the overarching MBIE research project '*Impacts, Barriers, and Enablers for a Circular Economy*', completed in early 2024.

Two key sub-projects of this research were:

1. Impacts of circular approaches on emissions, jobs, and other factors
2. Barriers, enablers, and approaches for a more circular economy

The '*Impacts of circular approaches on emissions jobs and other factors research'* (carried out by the same consortium partners as this research) took a critical material lens to the advanced manufacturing sector. New Zealand's reliance on imported materials and products is essential for sustaining its core capabilities, including the advanced manufacturing sector. The research explored leveraging the circular economy to enhance technological independence. This strategy is particularly relevant in the context of increasing global supply chain disruptions and the trend towards 'resource nationalism'.[i] It is complemented by efforts to boost domestic production and diversify supply sources.

Key potential interventions for critical materials in a circular economy context were identified as follows.

Table 12 Key potential interventions for critical materials in a circular economy context identified in 'Impacts of circular economy approaches on emissions, jobs and other factors'.

	Intervention	Target Impact	Timeframe	Classification
1	**Domestic recycling of critical minerals**	Reduce reliance on imports, conserve natural resources and enhance waste management.	Short to Medium Term	Incremental
2	**Enhancing product durability**	Reduce waste and resource use, extend product lifespan and promote sustainable consumption.	Medium Term	Incremental
3	**Remanufacturing**	Conserve resources, reduce waste and support a sustainable manufacturing sector.	Medium Term	Incremental
4	**Product-as-a-Service**	Promote resource efficiency, reduce ownership burden and foster sustainable business models.	Medium Term	Disruptive
5	**Design for reuse**	Facilitate product reuse, minimise waste and encourage sustainable design practices.	Long Term	Disruptive

The findings mirror many of the stakeholder insights from this research.

The *Barriers, enablers and approaches for a more circular economy* research, undertaken by The Connective, ARUP and Project: Moonshot, identified the following barriers, enablers and opportunity areas in manufacturing for a more circular economy:

Barriers:

- Undercapitalised SMEs plus high cost of capital
- Low venture capital availability in New Zealand
- Low workforce skills and capabilities in manufacturing
- Competitive behaviours between companies prevents collaboration on shared challenges
- Export-orientation inhibits domestic access to bio-materials
- Lack of strategic market-shaping by government
- Negative perception of manufacturing by workforce and business finance
- Poor existing knowledge of true benefits of circular material use
- Some trade agreements make building local supply chain resilience more challenging
- Limited support for early-stage innovators

Enablers:

- Global market pressures for low-carbon and 'green products' (e.g. regulatory drivers and disclosure requirements) – poor alignment is a risk to New Zealand's brand
- Government support – R&D, commercialisation and growth
- SME-dominated sector – small and agile
- Pockets of niche innovation (e.g. food, cleantech, mass timber and textiles)
- Government initiatives that support more circular business (e.g. Industry 4.0 and better data for material flows)
- Create policies to support manufacturing sectors critical to New Zealand's success, in a similar way to leading competitors

Opportunity areas:

- Utilise extensive bio-based resources to manufacture high-value products and increase productivity, (e.g. scaling timber manufacturing and manufacturing 'alternative meat and dairy')
- Strengthen national and regional value and supply chains for economic resilience and growth (e.g. identify and implement demonstration pilots for co-location and industrial symbiosis and Special Activation Precincts)
- Protect New Zealand's brand and ability to charge a premium for exports (e.g. phasing out unsustainable imports and introducing material passports)
- Recovery and remanufacturing to support a resilient low-carbon economy (e.g. metal recovery, healthcare and remanufacturing)
- Circular business models to drive innovation and mitigate under-capitalisation of manufacturing SMEs

13. Sensitivity analysis

International emissions factors and disaggregated emissions factors were two issues in top-down accounting that needed to be addressed, with assumptions tested through sensitivity analysis, as follows.

13.1. International emissions factors

As mentioned throughout this report in the sections that cover the top-down emissions account, NZ emissions intensities have been used as a proxy for imported goods and inputs to manufacturing. This is a simplification also used by Stats NZ to develop the NZ-wide consumption-based emission factors, and we have matched this methodology for consistency. Within the scope of this top-down assessment, it was not feasible to analyse each product within each sub-sector, accounting for the impacts of international procurement. We suggest that further effort in this area could better-reflect the emissions profile of imported goods, especially for products no longer manufactured in New Zealand.

To better understand the effect of using local production data as a proxy for overall manufacturing, a sensitivity analysis was completed using a select group of sub-sectors where imports have an important role in the overall consumption in NZ. International emissions factors, using external resources including EPDs, the GaBi Life Cycle Assessment database, and trade data, were used to create average intensities that are representative of how example products are manufactured internationally. These were created using a weighted average of product imports. This average takes the international emissions factor, translates it to an price-weighted intensity using Stats NZ Harmonised Trade data, and scales this by the import consumption at the relevant ANZSIC L4 category, while applying the domestic intensity to the domestic production component of total consumption.

Table 13 Results of this sensitivity analysis, for the targeted manufacturing sub-sectors.

ANZSIC06	Domestic Consumption Intensity (tCO_2e. / $ year)	Example product ANZSIC L4 - source	Hybrid Emissions Intensity (tCO_2e / $ year)
C:C17:C170 - Petroleum Refining and Petroleum and Coal Product Manufacturing	0.00051	Hybrid EF from GaBi Database – Petrol & Diesel Fuels	0.00038
C:C18:C183 - Fertiliser and Pesticide Manufacturing	0.00033	Hybrid EF from GaBi Database - Fertilisers	0.00036
C:C20:C203 - Cement, Lime, Plaster and Concrete Product Manufacturing	0.00048	Holcim Cement EPD	0.00053
C:C21:C211 - Basic Ferrous Metal Manufacturing	0.00084	GaBi Database: worldsteel LCI	0.00070
C:C21:C213 - Basic Non-Ferrous Metal Manufacturing	0.00084	International Aluminium Institute	0.00069
C:C23:C231 - Motor Vehicle and Motor Vehicle Part Manufacturing	0.00014	Hybrid EF, Volvo & Scania LCAs	0.00017

Figure 69 Percent difference between domestic consumption-based emissions intensity and hybrid international emissions intensity (tCO_2e / dollar - year)

Within the selected manufacturing sub-sectors modelled in this sensitivity analysis, there are estimated international emissions intensities that are both higher and lower than purely domestic proxies.

- Petroleum refining and coal products seems to be less emissions-intensive internationally, potentially due to economies of scale or improved efficiencies in the manufacturing process overseas. This may also be a matter of larger supply chain emissions in NZ because of the distance required to transport crude and refined oil to NZ, where transport is shorter for other countries. This international reduction is also notable given the significant electricity demand of refining, and NZ's relatively low-emissions grid.
- Both ferrous and non-ferrous primary metal manufacturing is more emissions intensive in the domestic process than using the estimated international factor. Considering NZ's large access to renewable electricity this is surprising, and we would expect that domestic non-ferrous manufacturing is less carbon-intensive than international averages. This is especially important for non-ferrous metals like aluminium which have a large electrical energy input to production.
- Domestic production of motor vehicles and parts is much less emissions intensive that overseas alternatives. This may be due to NZ manufacturing parts rather than complete vehicles, or assembling vehicles like campervans or buses from imported components – so the overall comparison is slightly skewed. Additionally, NZ's largely renewable energy makeup could be contributing to the lower emissions intensity.

From this short list of tests, we may assume the data using NZ proxies overall is within +/- 30% of the value if international emissions factors were used for imports.

13.2. Disaggregated emissions intensities

The second major assumption used throughout the top-down emissions account is the attribution of singular emissions intensities to multiple manufacturing sub-sectors when mapping from the National Accounts categories to ANZSIC06. This issue of one-to-many mappings meant some sub-sectors were given emissions factors that may not be accurate to their specific processes (e.g. in National Accounts, there is a category for Fruit, oil, cereal and other food manufacturing, but in ANZSIC06 these are 6 separate sub-sectors).

As this issue reduced granularity and accuracy in estimates, a sensitivity analysis was produced to estimate the magnitude of the effect this has had on the data overall. As with the international emissions factor's sensitivity analysis, this took the form of building emissions intensities using external resources and research and comparing these to the values from the top-down assessment. The example exercise for this sensitivity analysis was the metals and metal products ANZSIC sub-sectors, as there should ideally be a large range in the emissions factors between the many different sub-sectors here, but due to one-to-many mappings, ended up with only 2 unique emissions intensities (primary production and product manufacturing) shared by 9 sub-sectors.

This estimate works similarly to the previous sensitivity analysis, by finding emissions factors through external research including EPD and LCAs and converting them to emissions intensities through trade data from Stats NZ System of Harmonised Trade and published commodity prices for 2019.

Table 14 Example sensitivity analysis metals and metal products

ANZSIC06	Consumption Emissions Intensity (tCO_2e / \$ year)	Estimated Emissions Intensity (tCO_2e / \$ year)	Source
C:C21:C211 - Basic Ferrous Metal Manufacturing	0.00084	0.00324	NZ Steel EAF Fact Sheet - S&P Global - Steel Price Forecast
C:C21:C212 - Basic Ferrous Metal Product Manufacturing	0.00084	0.00017	EPA Allocative Baseline (Average) - S&P Global - Steel Price Forecast
C:C21:C213 - Basic Non-Ferrous Metal Manufacturing	0.00084	0.00200	International Aluminium Institute (CA scenario) - Business Insider - Aluminium Spot Price
C:C21:C214 - Basic Non-Ferrous Metal Product Manufacturing	0.00084	0.00008	GaBi Back-Calculation of Volvo LCA – Stats NZ Harmonised Trade
C:C22:C221 - Iron and Steel Forging	0.00019	0.00008	GaBi Back-Calculation of Volvo LCA – Stats NZ Harmonised Trade
C:C22:C222 - Structural Metal Product Manufacturing	0.00019	0.00017	Hybrid: Bluescope EPDs - Diff Welded Beams/cols + HRC, Rebar - Trading Economics - Steel Rebar
C:C22:C223 - Metal Container Manufacturing	0.00019	0.00008	GaBi Back-Calculation of Volvo LCA – Stats NZ Harmonised Trade
C:C22:C224 - Other Sheet Metal Product Manufacturing	0.00019	0.00009	Difference between Colorsteel EPD, Basic Ferrous Metal Manf – Stats NZ Harmonised Trade
C:C22:C229 - Other Fabricated Metal Product Manufacturing	0.00019	0.00008	GaBi Back-Calculation of Volvo LCA – Stats NZ Harmonised Trade

There is a large disparity between the emissions intensities allocated using the top-down environmental economic approach, and those calculated using EPDs and LCA data. This difference in values is potentially due to differences in methodology, or sensitivities between international commodity prices and local sale prices, as we didn't expect the emissions intensities (especially for non-ferrous metal production) to be so much larger than initially calculated. What we did expect is the much lower intensities for basic ferrous and non-ferrous metal products, compared to primary metal manufacturing itself. Surprisingly while the methodologies differ, the smaller sub-sectors including secondary metal products and fabricated items arrived close to the original top-down allocation.

Interpreting these comparisons should be done carefully considering the difference in methodologies. Both sensitivity analysis looks to recreate emissions intensities based on external resources like EPDs and LCA data. These typical attributional LCAs don't align with the environmental-economic modelling approach the top-down account was based on, which is most aligned with a consequential LCA with economic allocations.

Overall, due to the difference in methodologies it may not be suitable to dis-aggregate the sub-sectors this way – and a more suitable compromise could be the use of the less granular classification system instead of ANZSIC06 to display results. NZSIOC for example aligns almost exactly with NA06CC categories, and less information would be lost in conversion – it is the final step of translating to ANZSIC06 that results in the issues from one-to-many mapping.

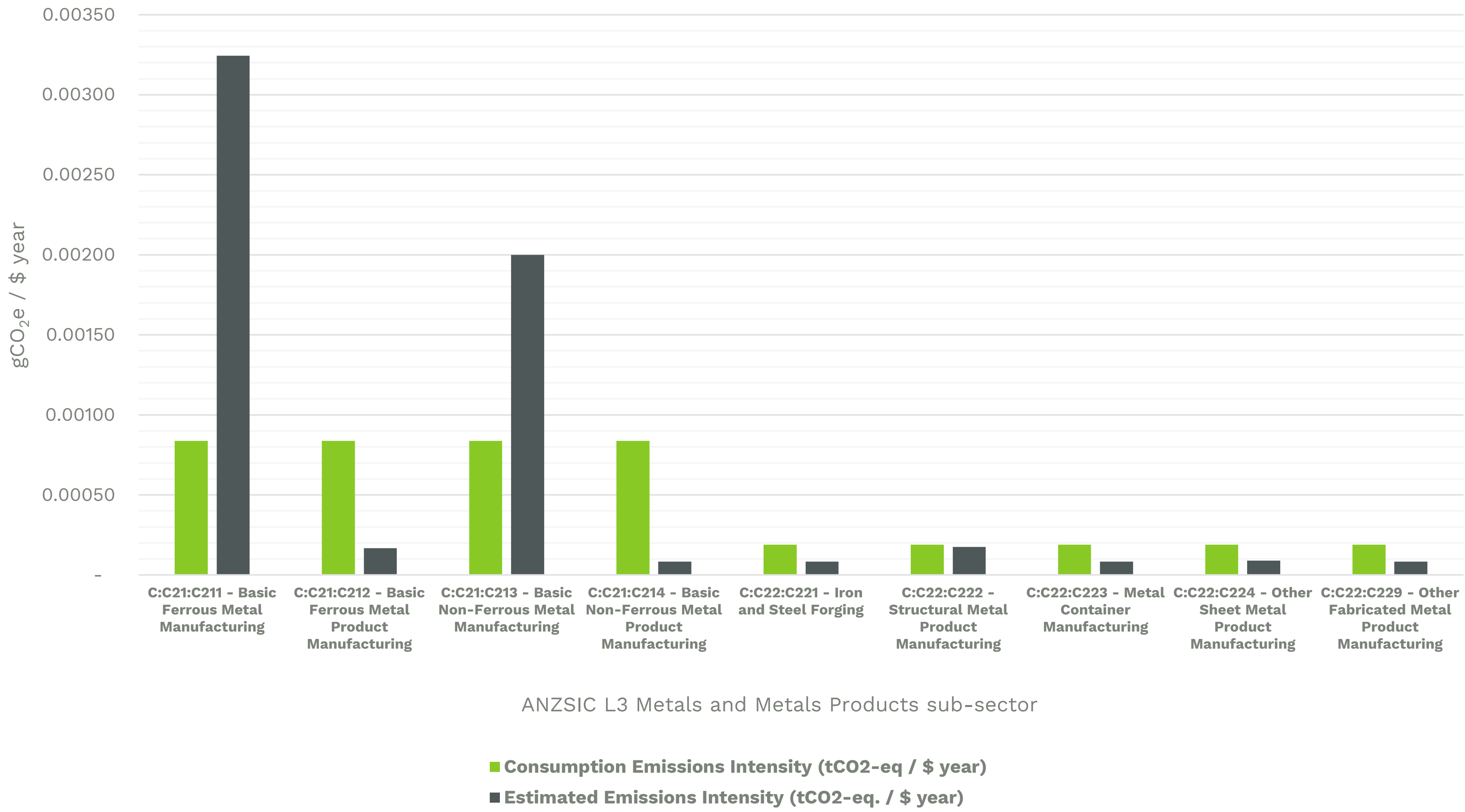

Figure 70 Sensitivity analysis of disaggregated emissions intensities for the metals and metal products manufacturing sector (tCO_2e / $ year), 2019 baseline

14. Opportunities

Like any business, manufacturers make business decisions that aim to improve or maintain their commercial standing – for example to reduce/manage risk, improve competitive advantage, reduce costs, increase profits, meet compliance requirements, create social licence, create brand identity.

Any opportunity or barrier to decarbonisation and circular economy needs to be grounded in that context. Furthermore, the more aligned those decarbonisation and circular economy solutions are with business needs, such as health and safety, access to markets, profit/loss, etc the more commercially attractive these solutions will be.

Barriers for manufacturers include:

- Access to capital, e.g. requiring short payback periods for large upfront costs, lower utilisation and payback for seasonal processes, potentially lower internal rate of return (IRR) compared to other investments, requirement for reasonable finance interest rates (e.g. farmers have seen an 86.5% increase in the cost of finance (Beef + Lamb New Zealand)).
- Internal competition for sustainability-related capital, e.g. prioritising funding between decarbonisation, circular economy, climate change adaptation, waste reduction.
- Prioritisation against other business needs and challenges, e.g. ongoing COVID-19 recovery, increasing costs (labour, freight, supply chain, finance), changes in markets and access to markets, regulatory compliance and inflation.
- Technical viability of technologies/processes in the NZ context, especially where they have not been demonstrated locally yet.
- Perceived or real risk of emerging technologies/processes making it difficult for a mature business to justify investment.
- Lack of knowledge or experience in deploying circular business models, including how to finance and how to derisk service-based models.
- Access to supply chains, e.g. energy, energy networks, equipment, product flows from other manufacturers. Some supply chains, such as for ongoing operation and maintenance of emerging technology, are yet to mature.
- Dispersion of assets – agri-based businesses spread throughout NZ with few areas of concentration. This can also require significant 'off site' investment for new or upgraded energy supply (e.g. transmission lines) and often these costs are difficult to share under the regulatory framework (i.e. transmission pricing methodology).
- Workforce capability and capacity across the sector, including knowledge sharing and associated IP / commercial confidentiality challenges.
- Lack of data sharing if considered commercially sensitive.

Enablers for manufacturers include:

- Cross-sector collaboration and insight sharing (while managing IP and commerciality) to enable business-to-business learning, build industry confidence in emerging solutions and support deployment at scale. This can

include establishment of regional and/or sub-sector-focused communities of practice through Living Labs, innovation hubs and precincts.
- Sector-specific guidance across the business journey, especially for SMEs who are earlier in the process: why they should pursue net-zero circular economy, the broader costs/benefits to their business, the steps they can take, and the support they can access.
- Technical and commercial consideration of how ‘higher risk’ solutions can be right-sized for an organisation to minimise risk while still delivering on desired business and net-zero circular economy outcomes.
- Accessible funding and financing mechanisms to help businesses overcome higher up-front capital costs and improve the commercial case for new emerging technologies. This is potentially the largest lever until costs of solutions decrease and become competitive with incumbent technologies/processes.
- Regional and cross-sector collaboration (while managing IP and commerciality) to develop and scale circular solutions, not only from a product flow perspective, but also through sharing energy infrastructure and supply chains.
- Government policy and regulation that is aligned with, encourages, and enables the transition (e.g. consenting requirements, electricity markets and shared infrastructure investment to enable low-cost renewable energy, levies, incentives). The GIDI programme also created the co-benefit of brand and marketing opportunities for organisations, enabling them to reach and influence a far-reaching audience.
- National and industry-specific circularity targets to enable tracking and investment.
- Bio-refining offers opportunities for forestry, agricultural, process, and post-consumer waste to be converted into new high value materials: diverting waste from decomposition and reducing emissions. Many forestry manufacturers also make use of their on-site biowaste (BioEnergy Facilities, 2023).
- Adoption of digital technologies, like artificial intelligence (AI), the Internet of Things (IoT), robotics, additive manufacturing, and digital twins support uptake of circular practices and innovation by enabling cost and resource efficiencies; gaining insights into supply chains; facilitating stakeholder collaboration; supporting exchange of resources and data; enabling digital testing of strategies; and optimising and monitoring resources and systems. Digital tools currently in use include logistics tracking software and dashboards such as eRoad and Mainfreight’s Maintel platform, with the latter including local and global freight emissions reporting (Mainfreight, 2022).

Opportunities for achieving decarbonisation and circular economy outcomes to create commercial alignment and realise business value include:

- Reducing cost per unit of production and/or increasing productivity through creating more value from the same raw inputs e.g. waste reduction, upcycling, energy efficiency, energy/heat recovery.
- Reducing risks: operational, market, concentration (diversified products and income).

- Reducing raw material supply chain, product logistics costs, constraints, associated supply chain emissions and improving supply chain resilience through less reliance on global supply chains.
- Creating skilled jobs through servicing assets rather than replacing them.
- Identifying and implementing demonstration pilots for co-location and industrial symbiosis and Special Activation Precincts. This would lead to enhanced use of waste flows as inputs across manufacturing sectors.
- Boosting domestic production through greater consumption of NZ-manufactured products that are currently imported.
- ‘Sweating’ assets, extending their lives and deferring capital investment in new assets.
- Improving brand differentiation, social licence to operate, regulatory compliance and sustainability credentials (e.g. sustainable packaging, water/resource intensity reduction, carbon reduction).
- Overcoming a labour constraint or reducing labour costs (e.g. fruit harvesting).
- Improving productivity of an asset (utilisation, reliability, and availability).
- Reducing overall operational expenses for the life of an asset.

15. Conclusions

This research project developed granular manufacturing emissions and waste profiles across sectors, including food and beverage, machinery and equipment, paper and wood, metal and metal products, chemicals and refining, plastics and rubber, and other manufacturing.

Significant differences and interconnections

Significant differences were observed among these sectors, but it was also evident that they were interconnected through resource flows and faced similar challenges, particularly in terms of limited manufacturing waste information.

Quantitative and qualitative methods

Our approach involved a combination of quantitative and qualitative methods to map each manufacturing sector comprehensively. This included considering local and global trade, resource inputs and outputs, logistics, processes, and the geographical distribution of activities. Examining imports and exports using a consumption and production perspective revealed valuable insights and highlighted issues related to imported emissions. We employed a sector-wide accounting approach based on economic considerations, combining top-down data set development with targeted deep dives into specific products using a bottom-up approach. The result is a range of visual representations showing key emission hotspots.

The sub-sectors in a nutshell

Food and beverage is the dominant manufacturing sector in NZ with production driven by dairy, meat, and other food exports. Machinery and equipment on the other hand has a low domestic emissions profile in comparison but is very strategic, enabling technology transformation and the delivery of services within the wider economy. Other manufacturing is highly differentiated and includes key products related to the built environment, such as cement, lime, plaster and glass, as well as textiles. This means a nuanced approach is required to solutions. In terms of interdependencies, we observed close links between food and beverage and other sectors relating to packaging manufacturing, which is dispersed by material type. Strong links were also identified between the chemicals and refining sector and the plastics and rubber sector. Supply chain-related emissions were significant across all sectors and must be considered.

Waste profiles in the sub-sectors

Common waste streams associated with manufacturing included personal protective equipment (PPE), packaging and potentially hazardous outputs. Organic waste was associated with food and beverage, wood and paper and other manufacturing. Further work is required to confirm manufacturing waste flows at a facility level and to encourage sharing of this information. Although plastics and rubber has a small proportion of emissions overall, waste is considered highly problematic for the sector with design and manufacturing stages enabling plastic reductions and recycling at end of life.

2019 data excludes recent changes

It is important to note that the data presented in this report reflects the state of sectors in 2019, and subsequent decarbonisation developments will be reflected in future profiles.

Notably, we expect the closure of Marsden Point to have had an impact on the chemicals and refining sector, while the commissioning of an electric arc furnace by NZ Steel will affect the metals and metal products sector in the future. Regular updates to this data set are crucial to provide more relevant information to government and industry and highlight changes over time.

Significant off-shoring of emissions

Our assessment of consumption-based and production-based emissions highlights a significant off-shoring of emissions across multiple sectors. For some imported products, including machinery, equipment and cement, the opportunity to directly influence the environmental impacts are limited to managing New Zealand demand. By employing models such as service life extension, access-based models, remanufacturing and repair to emission-heavy products we can reduce overall demand and make unavoidable emissions do more for our economy. Other products, including chemicals, fertilisers and timber products, represent opportunities to produce more of what we need domestically and reduce our import reliance. However, this approach needs to recognise that resilience and job creation may shift the impacts that are currently offshore back to New Zealand. This may increase domestic emissions but, ideally, reduce global emissions through reduced transportation and lower carbon domestic manufacturing.

Strong import dependencies

We observed strong import dependencies for most sub-sectors indicating a high degree of dependency on offshore production. Examples included chemicals for fertiliser production, feed for livestock, technology metals required by machinery and equipment, paper and timber panels, crude oil, petroleum fuels, basic chemical products, plastics, flat glass, textiles and cement, slag and ash for concrete production. Some of these, particularly fertilisers, technology metals and flat glass are likely to intersect with the forthcoming New Zealand Critical Minerals List, expected to be published in 2024. Stakeholders expressed interest in the opportunities this raises for shifting to greater levels of domestic production and independence or for applying business models that seek to extend the service life or utility of products, decoupling from supply risks by reducing demand and creating skilled jobs associated with reuse, remanufacturing and repair.

Positive industry engagement

Engagement activities, including workshops and interviews conducted between November 2023 and March 2024, provided an opportunity to share early findings and assess the value of the data with stakeholders. The development of this baseline data set has garnered interest and initial support from industry, and there is potential to build on this momentum through collaborative efforts to prioritise and develop decarbonisation and circular initiatives. Solutions aligned with business needs, such as health and safety, market access, and asset life cycles, were found to be more commercially attractive. However, further work is required to engage with Pakihi Māori (Māori business) to develop relevant data sets.

Evidence of existing circular practices

We found evidence of existing circular practices in New Zealand within and across different manufacturing sub-sectors integrated into 'business as usual'. Circular practices related to the bioeconomy were identified in the food and beverage and wood and paper sectors, where co-products, by-products, and waste materials are transformed. Key industries facilitating this include meat, dairy, and beverage, with advanced processing capabilities enabled by machinery and equipment and chemicals and refining, such as biorefining and precision fermentation. The metals, plastics, textiles, and construction industries also showcased existing recycling and re-manufacturing practices. Further investigation is required to determine the volume and value of these internal circular flows.

Strong regional presence

In terms of geographical distribution, manufacturing facilities are located throughout the country, with significant concentrations in major centres like Auckland and Christchurch. Manufacturing also has a strong regional presence, particularly in areas associated with primary production sources such as agriculture and forestry.

16. Recommendations

1. **Continue to develop and update the data in this report with industry to understand trends and changes to manufacturing emissions and waste.** Key FY2024 Stats NZ and improved MfE waste data will be available within the next 12 months. Regular updates over time and positioning of this data set within Aotearoa New Zealand emissions inventory are recommended.

2. **Collaborate with industry to identify, prioritise, and realise opportunities to develop a decarbonised, circular manufacturing sector, understand resource flows, and investigate opportunities for industrial symbiosis to reduce and divert waste.** Fostering greater collaboration with industry towards sub-sector resource flow transparency is critical, with sharing of manufacturing facility waste and diversion data by both tonnage and material composition considered critical. Next steps should include verification and quantification of resource input and output mapping that captures sub-sector products, co-products, by-products, and waste streams. This would require active engagement with New Zealand manufacturers, and the waste and resource recovery sector, and include primary data collection support and economic analysis related to identified circular practice value.

3. **Support adopting digital tools (e.g. GIS, digital product passports) to help the industry collect and communicate data. This will encourage product stewardship, help the industry track emissions, and support international trade.** This may include incorporation of GIS portals, digital twins, digital product passports and data to support asset management decisions and low-carbon plant renewals, identification and tracking of resource flows, product stewardship and emissions tracking throughout value chains. This is considered particularly important for key trade commodities given the rapidly emerging requirements for digital reporting in the EU.

4. **Investigate ways to make assets last longer (e.g. investment and depreciation levers).** Asset durability is an important intervention point not only for improved technologies, but for decarbonisation, circular solutions, critical minerals supply risk mitigation and climate resilience and adaptation.

5. **Investigate and address data gaps, limitations and assumptions further, including:**

   - **Consumption-based emissions (including from imported goods**), as discussed in the Sensitivity Analysis section to understand emissions impacts of imported goods and emissions intensities at a more granular level e.g. ANZSIC L4.
   - **Stocks and flows (e.g. lifespans, durability, replacement scenarios)** to better understand lifespans or durability of existing resources in use. This is particularly relevant to product-as-a-Service and leasing models, as well as long-lifetime products in the built environment and machinery and equipment sectors.
   - **Identify critical minerals links and circular economy strategies to improve resilience.** Integration of critical minerals linkages based on the forthcoming NZ Critical Minerals List to identify and prioritise circular economy interventions aimed

at minimising risks from import dependencies identified in multiple sub-sectors and enhancing NZ resilience.

- **Waste data (e.g. volumes and flows) improvements.** Verification of manufacturing waste outputs is critical, and data on internal circulation, resale and industrial monofills is needed to enhance understanding.
- **Verification and quantification of 'potentially hazardous' waste streams** associated with manufacturing sub-sectors.

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Abbreviations and glossary

Term	Definition
Anaerobic digestion	Biological process where micro-organisms break down organic matter without the presence of oxygen, producing biogas.
Biobased and Biochar	Products derived from biological sources, and a form of charcoal produced from organic matter, often used as a soil enhancer.
Bioeconomy	The bioeconomy refers to parts of the economy that use renewable biological resources to produce food, products, and energy.
Bioproduct, Biopolymers, Biochemicals	Products derived from renewable biological sources.
Biomass	Organic materials.
Built environment	Human-made structures.
Carbon footprint	The total amount of greenhouse gases, especially carbon dioxide, emitted directly or indirectly by an individual, organisation, event, or product.
Circular economy	An economic system that promotes the continual use and reuse of resources, minimising waste through recycling, refurbishing and sustainable practices.
Circularity	The degree to which a system follows circular economy principles, emphasising sustainability and reduced environmental impact.
Class 1 landfill	In New Zealand, these landfills are designed to accept municipal solid waste which includes household waste, commercial waste and other wastes.
Class 2 landfill	In New Zealand, these landfills are designed to accept non-putrescible wastes including construction and demolition waste such as wood products, asphalt, plasterboard, insulation and other inert industrial wastes.
Class 3 landfill	In New Zealand, these landfills are designed to accept hazardous waste such as asbestos, contaminated soil, and other hazardous materials.
Class 4 landfill	In New Zealand, these landfills accept inert materials like clay, soil and rock, as well as concrete or brick.
Class 5 cleanfill	In New Zealand, these landfills accept only virgin excavated natural material, such as clay, soil or rock for disposal.
Critical Material	A material generally deemed by business interests to be commercially essential, in which significant supply risks have been identified.
Critical Mineral	An element or material extracted from mineral ores, deemed essential by government agencies to be essential for the national economy or national security, in which significant supply risks have been identified.
Decoupling	Breaking the link between economic growth and resource consumption.

Term	Definition
Design for disassembly	Designing products to be easily taken apart for recycling or reuse at the end of their life cycle.
Design for reuse	Designing products to be used multiple times.
Downcycling	Recycling a material in a way that decreases its quality or value.
Extended Producer Responsibility (EPR)	The concept that manufacturers should take responsibility for the entire lifecycle of their products, including recycling and proper disposal.
Farm dump	In New Zealand, refers to an informal waste disposal site located on a farm for the disposal of non-natural rural waste from agricultural activities, including metal, timber, plastic, glass, batteries and construction and demolition waste.
Feedstocks	Raw materials used in industrial processes, particularly those used for biofuel or bioproduct production.
GHG	Greenhouse gases. Atmospheric gases that trap heat from the sun, thereby warming the Earth's surface. They include carbon dioxide, methane, nitrous oxide, and fluorinated gases.
Industrial ecology	The study of the ways in which industrial systems do and/or should mimic systems in nature.
Life Cycle Assessment (LCA)	A method of evaluating the environmental impact of a product throughout its entire lifecycle, from raw material extraction to disposal.
Linear economic model	A traditional economic approach where resources are extracted, used to make products, and then disposed of as waste.
Mātauranga Māori	Traditional Māori knowledge and wisdom, often integrated with sustainable practices in the circular economy.
Material flows	The movement of materials through the various stages of production, use, and disposal.
Material footprint	The amount of raw materials and resources used to produce goods and services, indicating the environmental impact of consumption.
Methane emissions	Gases released into the atmosphere, often from organic waste decomposition, contributing to climate change.
Micro, Meso, and Macro Scales	Different levels of analysis, from small individual components (micro) to larger systems (macro).
Microcircularity	Circular economy principles applied at a small scale, such as individual products or components.
Nature regeneration	The process of restoring and renewing ecosystems to improve their health and sustainability.
Organic waste	Biodegradable waste from plant or animal sources, such as food scraps and yard trimmings.
Product-as-a-Service	A business model where individuals or entities pay for the utility of a product rather than its ownership, encouraging a focus on durability and reuse.

Term	Definition
Quantitative indicators	Measurable data used to assess and quantify aspects of the circular economy, such as resource use or recycling rates.
Qualitative assessment	Evaluation based on non-numeric criteria, focusing on the qualities and characteristics of a system or process.
Recyclate	Recycled material derived from the processing of waste.
Regenerative design	Designing products and systems with the intention of not only reducing harm but also actively contributing to the restoration and regeneration of ecosystems.
Resource efficiency	Using resources in a way that maximises their value and minimises waste.
Sankey diagram	A visual representation of energy, material, or flow processes, often used to illustrate resource efficiency and waste reduction.
Supplementary cementitious materials	Materials added to cement to enhance its properties, often derived from industrial by-products.
Upcycling	The process of transforming waste materials or unwanted products into items of greater value or quality.
Volatile chemicals	Substances that easily evaporate into the air, often associated with environmental and health concerns.
Waste hierarchy	A ranking of waste management strategies in order of their environmental impact, typically prioritising prevention, reuse, and recycling, with disposal as a last resort.
Waste valorisation	The process of extracting value from waste materials, often through recycling or repurposing.

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Annexes

A.1. Research methodology

The emissions and waste data set provides a baseline of greenhouse gas (GHG) emissions and waste streams for seven sub-sectors across the NZ advanced manufacturing sector. The methodology to develop this data set involves two analytical approaches to ensure accuracy and reduce uncertainty in final figures:

The **top-down** approach takes national-level data from trusted sources (largely Stats NZ) and breaks it down using standard data structures, mapping between economic and emissions-related formats to match concordance. For GHG emissions, calculations are based on equivalent economic values available through the national accounts input-output tables. For waste, available national, territorial authority and industry data is sought for access and use.

The **bottom-up approach** relies on material flow analysis (MFA), based loosely on ISO14051:2011 Material Cost Flow Analysis (MFCA). It examines the flow of inputs and outputs within the manufacturing process. These flows are modelled using the Australian and New Zealand Standard Industrial Classification (ANZSIC) format at Level 3. The approach uses the MFA framework to identify and map GHG emissions and waste flows associated with each sub-sector, and scales values based on the value/output of each. Quantitative data for product and waste flows (as well as information about facilities and businesses) is preferred where possible and supported by qualitative data where required. This data is sourced from desktop research and supported by industry engagement.

Emissions data is calculated using both a production- and consumption-based approach. Production-based emissions account only for the central manufacturing process (plant used to process raw materials, and any associated direct emissions to atmosphere). Consumption-based emissions include production-based emissions and the emissions embodied in the upstream and downstream supply chains for an industry, including the final end use of a manufactured good by a consumer. Consumption-based emissions also consider the amount of goods consumed in NZ, rather than the total amount manufactured in NZ (this accounts for both imports and exports).

Both approaches consider the potential sources of emissions and waste identified in the Greenhouse Gas Protocol. The system boundary is determined by the relevance of the sources to circular economy practices and insights for decarbonisation and waste management. The project considers scopes 1, 2 and 3 GHG emissions, with scope 3 inclusions and exclusions as follows (Table 15).

Table 15 Scope 3 Sources

Included	Excluded
Purchased goods and services	Capital goods
Upstream transportation/distribution	Employee commuting
Waste generated in operations	Processing of sold products
Business travel	Franchises
Upstream leased assets	Investments
Downstream transportation/distribution	
Use of sold products	
End-of-life treatment of sold products	
Downstream leased assets	

To address limited data availability, industry consultation and qualitative data procurement are prioritised. The guidance of Te Kahui Raraunga is followed to ensure appropriate management and use of Māori data, considering tikanga Māori.

The methodology follows Stats NZ's guidance on preparing Tier 1 statistics, ensuring accuracy, transparency, and addressing uncertainty. International Panel for Climate Change (IPCC) guidance is employed to attribute uncertainty to climate-related data, using a confidence scale with dimensions of ‘agreement’ and ‘evidence’.

Overall, this data set development methodology combines quantitative and qualitative data to establish a comprehensive understanding of GHG emissions and waste across the seven sub-sectors in the advanced manufacturing sector. The approach ensures data accuracy, reduces uncertainty, promotes industry consultation, and considers cultural guidelines for data governance.

Table 16 ANZSIC L2, L3, L4

L2	L3	L4
C:C11 C:C12 Food and beverage	C:C11:C111 - Meat and Meat Product Manufacturing	C:C11:C111:C111100- Meat Processing
		C:C11:C111:C111200- Poultry Processing
		C:C11:C111:C111300- Cured Meat and Smallgoods Manufacturing
	C:C11:C112- Seafood Processing	C:C11:C112:C112000- Seafood Processing
	C:C11:C113- Dairy Product Manufacturing	C:C11:C113:C113100- Milk and Cream Processing
		C:C11:C113:C113200- Ice Cream Manufacturing
		C:C11:C113:C113300- Cheese and Other Dairy Product Manufacturing
	C:C11:C114- Fruit and Vegetable Processing	C:C11:C114:C114000- Fruit and Vegetable Processing
	C:C11:C115 - Oil and Fat Manufacturing	C:C11:C115:C115000 Oil and Fat Manufacturing
	C:C11:C116- Grain Mill and Cereal Product Manufacturing	C:C11:C116:C116100- Grain Mill Product Manufacturing
		C:C11:C116:C116200- Cereal, Pasta and Baking Mix Manufacturing
	C:C11:C117 - Bakery Product Manufacturing	C:C11:C117:C117100- Bread Manufacturing (Factory based)
		C:C11:C117:C117200- Cake and Pastry Manufacturing (Factory based)
		C:C11:C117:C117300- Biscuit Manufacturing (Factory based)
		C:C11:C117:C117400- Bakery Product Manufacturing (Non-factory based)
	C:C11:C118 - Sugar and Confectionery Manufacturing	C:C11:C118:C118100- Sugar Manufacturing
		C:C11:C118:C118200- Confectionery Manufacturing
	C:C11:C119- Other Food Product Manufacturing	C:C11:C119:C119100- Potato, Corn and Other Crisp Manufacturing
		C:C11:C119:C119200- Prepared Animal and Bird Feed Manufacturing
		C:C11:C119:C119900- Other Food Product Manufacturing n.e.c.
	C:C12:C121- Beverage Manufacturing	C:C12:C121:C121100- Soft Drink, Cordial and Syrup Manufacturing
		C:C12:C121:C121200- Beer Manufacturing
		C:C12:C121:C121300- Spirit Manufacturing
		C:C12:C121:C121400- Wine and Other Alcoholic Beverage Manufacturing
	C:C12:C122 - Cigarette and Tobacco Product Manufacturing	C:C12:C122:C122000- Cigarette and Tobacco Product Manufacturing
C:C14		C:C14:C141:C141100- Log Sawmilling

L2	L3	L4
C:C15 C:C16 Wood and paper	C:C14:C141- Log Sawmilling and Timber Dressing	C:C14:C141:C141200- Wood Chipping
		C:C14:C141:C141300- Timber Resawing and Dressing
	C:C14:C149- Other Wood Product Manufacturing	C:C14:C149:C149100- Prefabricated Wooden Building Manufacturing
		C:C14:C149:C149200- Wooden Structural Fitting and Component Manufacturing
		C:C14:C149:C149300- Veneer and Plywood Manufacturing
		C:C14:C149:C149400- Reconstituted Wood Product Manufacturing
		C:C14:C149:C149900- Other Wood Product Manufacturing n.e.c.
	C:C15:C151- Pulp, Paper and Paperboard Manufacturing	C:C15:C151:C151000- Pulp, Paper and Paperboard Manufacturing
	C:C15:C152- Converted Paper Product Manufacturing	C:C15:C152:C152100- Corrugated Paperboard and Paperboard Container Manufacturing
		C:C15:C152:C152200- Paper Bag Manufacturing
		C:C15:C152:C152300- Paper Stationery Manufacturing
		C:C15:C152:C152400- Sanitary Paper Product Manufacturing
		C:C15:C152:C152900- Other Converted Paper Product Manufacturing
	C:C16:C161- Printing	C:C16:C161:C161100- Printing
		C:C16:C161:C161200- Printing Support Services
	C:C16:C162- Reproduction of Recorded Media	C:C16:C162:C162000- Reproduction of Recorded Media
C:C17 C:C18 Chemical and Refining	C:C17:C170- Petroleum Refining and Petroleum and Coal Product Manufacturing	C:C17:C170:C170100- Petroleum Refining and Petroleum Fuel Manufacturing
		C:C17:C170:C170900- Other Petroleum and Coal Product Manufacturing
	C:C18:C181- Chemical Manufacturing	C:C18:C181:C181100- Industrial Gas Manufacturing
		C:C18:C181:C181200-Basic Organic Chemical Manufacturing
		C:C18:C181:C181300-Basic Inorganic Chemical Manufacturing
	C:C18:C182- Basic Polymer Manufacturing	C:C18:C182:C182100- Synthetic Resin and Synthetic Rubber Manufacturing
		C:C18:C182:C182900- Other Basic Polymer Manufacturing
	C:C18:C183-Fertiliser and Pesticide Manufacturing	C:C18:C183:C183100- Fertiliser Manufacturing
		C:C18:C183:C183200-Pesticide Manufacturing
	C:C18:C184- Pharmaceutical and Medicinal Product Manufacturing	C:C18:C184:C184100- Human Pharmaceutical and Medicinal Product Manufacturing

L2	L3	L4
		C:C18:C184:C184200- Veterinary Pharmaceutical and Medicinal Product Manufacturing
	C:C18:C185-Cleaning Compound and Toiletry Preparation Manufacturing	C:C18:C185:C185100- Cleaning Compound Manufacturing
		C:C18:C185:C185200 -Cosmetic and Toiletry Preparation Manufacturing
	C:C18:C189-Other Basic Chemical Product Manufacturing	C:C18:C189:C189100- Photographic Chemical Product Manufacturing
		C:C18:C189:C189200- Explosives Manufacturing
		C:C18:C189:C189900- Other Basic Chemical Product Manufacturing n.e.c.
C:C19 Plastic and Rubber	C:C19:C191- Polymer Product Manufacturing	C:C19:C191:C191100- Polymer Film and Sheet Packaging Material Manufacturing
		C:C19:C191:C191200- Rigid and Semi-Rigid Polymer Product Manufacturing
		C:C19:C191:C191300- Polymer Foam Product Manufacturing
		C:C19:C191:C191400- Tyre Manufacturing
		C:C19:C191:C191500-Adhesive Manufacturing
		C:C19:C191:C191600- Paint and Coatings Manufacturing
		C:C19:C191:C191900- Other Polymer Product Manufacturing
	C:C19:C192- Natural Rubber Product Manufacturing	C:C19:C192:C192000- Natural Rubber Product Manufacturing
C:C21 C:C22 Metals and Metals Manufacturing	C:C21:C211- Basic Ferrous Metal Manufacturing	C:C21:C211:C211000- Iron Smelting and Steel Manufacturing
	C:C21:C212- Basic Ferrous Metal Product Manufacturing	C:C21:C212:C212100- Iron and Steel Casting
		C:C21:C212:C212200- Steel Pipe and Tube Manufacturing
	C:C21:C213- Basic Non-Ferrous Metal Manufacturing	C:C21:C213:C213100- Alumina Production
		C:C21:C213:C213200- Aluminium Smelting
		C:C21:C213:C213300- Copper, Silver, Lead and Zinc Smelting and Refining
		C:C21:C213:C213900- Other Basic Non-Ferrous Metal Manufacturing
	C:C21:C214- Basic Non-Ferrous Metal Product Manufacturing	C:C21:C214:C214100- Non-Ferrous Metal Casting
		C:C21:C214:C214200- Aluminium Rolling, Drawing, Extruding
		C:C21:C214:C214900- Other Basic Non-Ferrous Metal Product Manufacturing
	C:C22:C221- Iron and Steel Forging	C:C22:C221:C221000- Iron and Steel Forging

L2	L3	L4
	C:C22:C222- Structural Metal Product Manufacturing	C:C22:C222:C222100- Structural Steel Fabricating
		C:C22:C222:C222200- Prefabricated Metal Building Manufacturing
		C:C22:C222:C222300- Architectural Aluminium Product Manufacturing
		C:C22:C222:C222400- Metal Roof and Guttering Manufacturing (except Aluminium)
		C:C22:C222:C222900-Other Structural Metal Product Manufacturing
	C:C22:C223- Metal Container Manufacturing	C:C22:C223:C223100- Boiler, Tank and Other Heavy Gauge Metal Container Manufacturing
		C:C22:C223:C223900-Other Metal Container Manufacturing
	C:C22:C224- Other Sheet Metal Product Manufacturing	C:C22:C224:C224000- Other Sheet Metal Product Manufacturing
	C:C22:C229- Other Fabricated Metal Product Manufacturing	C:C22:C229:C229100- Spring and Wire Product Manufacturing
		C:C22:C229:C229200- Nut, Bolt, Screw and Rivet Manufacturing
		C:C22:C229:C229300- Metal Coating and Finishing
		C:C22:C229:C229900- Other Fabricated Metal Product Manufacturing n.e.c.
C:C23 C:C24 Machinery and equipment	C:C23:C231- Motor Vehicle and Motor Vehicle Part Manufacturing	C:C23:C231:C231100- Motor Vehicle Manufacturing
		C:C23:C231:C231200- Motor Vehicle Body and Trailer Manufacturing
		C:C23:C231:C231300- Automotive Electrical Component Manufacturing
		C:C23:C231:C231900- Other Motor Vehicle Parts Manufacturing
	C:C23:C239- Other Transport Equipment Manufacturing	C:C23:C239:C239100- Shipbuilding and Repair Services
		C:C23:C239:C239200- Boatbuilding and Repair Services
		C:C23:C239:C239300- Railway Rolling Stock Manufacturing and Repair Services
		C:C23:C239:C239400- Aircraft Manufacturing and Repair Services
		C:C23:C239:C239900- Other Transport Equipment Manufacturing n.e.c.
	C:C24:C241- Professional and Scientific Equipment Manufacturing	C:C24:C241:C241100- Photographic, Optical and Ophthalmic Equipment Manufacturing
		C:C24:C241:C241200- Medical and Surgical Equipment Manufacturing
		C:C24:C241:C241900- Other Professional and Scientific Equipment Manufacturing

L2	L3	L4
	C:C24:C242- Computer and Electronic Equipment Manufacturing	C:C24:C242:C242100- Computer and Electronic Office Equipment Manufacturing
		C:C24:C242:C242200- Communication Equipment Manufacturing
		C:C24:C242:C242900- Other Electronic Equipment Manufacturing
	C:C24:C243- Electrical Equipment Manufacturing	C:C24:C243:C243100- Electric Cable and Wire Manufacturing
		C:C24:C243:C243200- Electric Lighting Equipment Manufacturing
		C:C24:C243:C243900- Other Electrical Equipment Manufacturing
	C:C24:C244- Domestic Appliance Manufacturing	C:C24:C244:C244100- Whiteware Appliance Manufacturing
		C:C24:C244:C244900- Other Domestic Appliance Manufacturing
	C:C24:C245- Pump, Compressor, Heating and Ventilation Equipment Manufacturing	C:C24:C245:C245100- Pumps and Compressor Manufacturing
		C:C24:C245:C245200- Fixed Space Heating, Cooling and Ventilation Equipment Manufacturing
	C:C24:C246- Specialised Machinery and Equipment Manufacturing	C:C24:C246:C246100- Agricultural Machinery and Equipment Manufacturing
		C:C24:C246:C246200- Mining and Construction Machinery Manufacturing
		C:C24:C246:C246300- Machine Tool and Parts Manufacturing
		C:C24:C246:C246900- Other Specialised Machinery and Equipment Manufacturing
	C:C24:C249- Other Machinery and Equipment Manufacturing	C:C24:C249:C249100- Lifting and Material Handling Equipment Manufacturing
		C:C24:C249:C249900- Other Machinery and Equipment Manufacturing n.e.c.
C:C13 C:C20 C:C25 Other Manufacturing	C:C13:C131 Textile Fibre, Yarn and Woven Fabric Manufacturing	C:C13:C131:C131100- Wool Scouring
		C:C13:C131:C131200- Natural Textile Manufacturing
		C:C13:C131:C131300-Synthetic Fibre Textile Manufacturing
	C:C13:C132- Leather Tanning and Fur Dressing	C:C13:C132:C132000- Leather Tanning, Fur Dressing and Leather Product Manufacturing
	C:C13:C133- Textile Product Manufacturing	C:C13:C133:C133100- Textile Floor Covering Manufacturing
		C:C13:C133:C133200- Rope, Cordage and Twine Manufacturing
		C:C13:C133:C133300- Cut and Sewn Textile Product Manufacturing
		C:C13:C133:C133400- Textile Finishing and Other Textile Product Manufacturing

L2	L3	L4
	C:C13:C134- Knitted Product Manufacturing	C:C13:C134:C134000- Knitted Product Manufacturing
	C:C13:C135- Clothing and Footwear Manufacturing	C:C13:C135:C135100- Clothing Manufacturing
		C:C13:C135:C135200- Footwear Manufacturing
	C:C20:C201- Glass and Glass Product Manufacturing	C:C20:C201:C201000- Glass and Glass Product Manufacturing
	C:C20:C202- Ceramic Product Manufacturing	C:C20:C202:C202100- Clay Brick Manufacturing
		C:C20:C202:C202900- Other Ceramic Product Manufacturing
	C:C20:C203- Cement, Lime, Plaster and Concrete Product Manufacturing	C:C20:C203:C203100 -Cement and Lime Manufacturing
		C:C20:C203:C203200- Plaster Product Manufacturing
		C:C20:C203:C203300- Ready-Mixed Concrete Manufacturing
		C:C20:C203:C203400- Concrete Product Manufacturing
	C:C20:C209- Other Non-Metallic Mineral Product Manufacturing	C:C20:C209:C209000- Other Non-Metallic Mineral Product Manufacturing
	C:C25:C251- Furniture Manufacturing	C:C25:C251:C251100- Wooden Furniture and Upholstered Seat Manufacturing
		C:C25:C251:C251200- Metal Furniture Manufacturing
		C:C25:C251:C251300-Mattress Manufacturing
		C:C25:C251:C251900- Other Furniture Manufacturing
	C:C25:C259- Other Manufacturing	C:C25:C259:C259100- Jewellery and Silverware Manufacturing
		C:C25:C259:C259200- Toy, Sporting and Recreational Product Manufacturing
		C:C25:C259:C259900- Other Manufacturing n.e.c.

A.2. Top-down analysis

A.2.1. GHG emissions methodology

The greenhouse gas (GHG) emissions accounts for the advanced manufacturing sector were completed using a combination of two quantitative modelling techniques, supported by qualitative information from desktop research and industry engagement. This account was completed using a consumption-based approach, which sought to account for not only the manufacturing process itself, but the emissions from the supply chain and direct use by domestic consumers. Production-based modelling was included for comparison.

The consumption-based GHG emissions account was completed quantitatively using both a top-down and bottom-up approach, as each of them have strengths and weaknesses.

The top-down approach was an Environmental Input-Output Life-Cycle Assessment (EIO-LCA) model, which uses aggregated, industry level emissions data and national economic input-output tables to calculate emissions across an industry's supply chain. The EIO-LCA provided excellent coverage, with very few gaps in data to address, but sacrificed granularity due to the use of highly aggregated data. The bottom-up approach was a Material Flow Analysis (MFA), which used quantities of stocks and flows of materials in the industries to calculate their associated emissions. MFA can experience quality issues due to material mass and quantity data gaps but provided more granularity than top-down.

Our team's overall goal was to complete the MFA as our primary data source, and to sense-check and upscale the values using the EIO-LCA – using the strengths of both approaches and minimising their weaknesses. Assumptions and estimations made throughout both the top-down and bottom-up accounts were sense-checked with industry, including checking values against relevant climate-related disclosures, and through direct workshops, interviews, and industry engagement. The outcome of this exercise was a set of figures and visuals including Sankey diagrams and heatmaps of GHG emissions for each advanced manufacturing sub-sector.

A.2.2. Limitations and assumptions

International emissions intensities

A significant limitation was accounting for emission intensities for products and materials produced overseas. NZ relies on imports, both for the raw material inputs to manufacturing and finished manufactured goods for domestic consumption. Our domestic manufacturing processes and supply chains were not representative of international counterparts, due to our differences in technology, productivity, energy sources, and a range of other factors. These differences mean imported materials and products have varied emissions profiles compared to those produced in NZ. There was difficulty in accounting for the different emissions of so many materials and products from the range of countries we import from. In lieu of this exercise, we used NZ emissions intensities as a proxy – a common technique in similar accounts. Sensitivity analysis with key imports was intended to determine the significance of this assumption.

Data classification and concordance

Within the top-down account of GHG emissions, many different environmental and economic data sources were required. A challenge of this task was ensuring each data set could be used in a suitable way, while losing the minimum amount of information through conversions between standards.

The reference emissions data sets and the economic input-output data sets (both provided by Stats NZ) were not formatted using the same standard industry breakdowns. The data needed conversion between two classification standards to be able to be used in its final form, with these conversions introducing potential variance due to the imperfect concordance.

The reference emissions data from Stats NZ is provided in the NZ Standard Industrial Output Classification (NZSIOC) format, which requires conversion to the National Accounts 2006 Classification Code (NA06CC) to integrate with the economic data in the input-output tables. A conversion to the Australia-NZ Standard Industrial Classification 2006 (ANZSIC06) is then required to achieve data set format requirements. Emissions intensities (carbon dioxide-equivalent emissions per $) are applied to total domestic consumption to calculate total emissions. Import and export values were then required by converting from the NZ Harmonised System Classification (NZHSC) to ANZSIC06.

Each time information requires conversion to a different standard there is a potential error introduced. This was pronounced where mappings are many-to-one, or one-to-many. An example of this is mapping consumption-based emissions intensities in the NA06CC format to ANZSIC06, where the one-to-many mapping results in multiple manufacturing sub-sectors being allocated the same emissions intensity where they should be differentiated. Conversion errors could be reduced by Stats NZ standardising classification systems for these data releases.

Aggregation of reference data

Some data granularity is limited due to the availability of data that could contain confidential commercial information. An example of this is the domestic production figures for manufacturing, where public data is aggregated to a higher level. This has been resolved through a Stats NZ custom data request for disaggregated manufacturing data, which enabled calculating emissions to ANZSIC Level 3. Although this has been a significant improvement, the disaggregated data set included multiple ANZSIC06 sub-sectors where data was blank. External data sources have been used to estimate these figures, most significantly for the primary steel and aluminium industries (Clark, Westpac Industry Insights: Metallic and non-metallic mineral products manufacturing, 2019), and the beverage and tobacco industries (Coriolis Research, 2012).

We note that disaggregated and standardised production data is required to best understand hotspots and opportunities for the sector. However, we recognise that withholding this information from the public is sometimes required where there may be monopoly or duopoly dynamics within sub-sectors, or if there are wider data collection issues.

Split-gas accounting approach

Another limitation of this exercise so far is the use of carbon dioxide-equivalent emissions as a unit. This makes accounting easier and enables the medium- to long-term global warming potential of sub-sectors to be accurately compared – but then fails to capture the differences in their warming effect in the short term. We know, for example, that much of the emissions from the food and beverage sector's supply chain is methane from live animals in the agriculture sector. Methane has a much higher global warming potential than carbon dioxide but is far shorter lived. These intricacies provide further levels of insights that are currently not available from the data. Taking a split-gas accounting approach may be a useful improvement for future developments.

A.3. Bottom-up analysis

A.3.1. Qualitative resource flow mapping methodology

A comprehensive desktop literature review was conducted in September and October 2023 to identify existing data sets publicly available, and those that might be available upon request. This included review of available data sets, research, and other relevant documents from MfE, BRANZ, Stats NZ, industry such as Plastics NZ, consultancies such as Eunomia, and territorial authorities such as local and regional councils. The review also identified stakeholders and organisations that would be able to provide relevant manufacturing and industrial waste source information such as waste service providers, landfill operators and resource recovery facilities.

A gap analysis then assessed available data quality and usefulness by advanced manufacturing sub-sector. It was found that waste sources data sets and current publicly available data was very limited and additional data would be required to progress waste data set development. It was anticipated that the gaps identified in the literature review would be sufficiently filled through the workshop and interview engagement step with businesses in the advanced manufacturing sector.

In response to limited available waste data and the need to understand the current state of waste in relation to advanced manufacturing, in-depth qualitative waste flow mapping was carried out in November to explore existing practices and opportunities across all sub-sectors at ANZSIC Level 4 product level – this was undertaken through desktop research. It looked at almost 140 different product value chains to identify existing resource inputs and outputs shared within and between sub-sectors, common waste outputs, and established circular economy examples.

For each sub-sector, the following qualitative data was collected:

- Production inputs
- Product/co-products
- By-products
- Waste at factory gate, including solid waste and wastewater
- Consumer end-of-life scenarios e.g. cradle to grave, cradle to cradle.

Planned engagement was an important opportunity to gather primary data through targeted questions and facility-level data requests to individual organisations for further aggregation by sub-sector.

A.3.2. Limitations and assumptions

Waste data methodology consistency is a challenge. There is a lack of mandatory or standardised data reporting requirements for licensed waste operators, as well as a lack of a coordinated central repository for the gathering, analysing, and disseminating of waste data due to commercial sensitivities. We understand this is actively being addressed by MfE and improvements can be expected in 2024 through recent changes to landfill waste reporting requirements.

In general, sector-based waste information linked to source remains a significant knowledge gap. It is difficult to work backwards from national- or regional-level waste data to source and therefore it is critical to understand potential advanced manufacturing resource flows and waste streams associated with manufacturing production, which vary significantly by sub-sector. This also includes understanding potentially hazardous waste and resource flows.

The best data available is residential waste in some regions, depending on territorial authority waste auditing quality. This has limitations in its application to advanced manufacturing as a sector, although we recognise close connections with the production of consumer products and ultimately household end-of-life pathways. Gaps for regionally available waste data also include access to tonnage and composition information on material disposed of, processed out of region, and diverted.

Rural waste managed on farms is a known gap in waste data and is difficult to quantify, which impacts upstream waste for advanced manufacturing, particularly food and beverage.

There is some data available for Construction and Demolition (C&D) waste which has some crossover with advanced manufacturing. However, there is limited information in the public domain about C&D material landfill, clean fills and other land disposal sites, diversion by volume and type, and quantities and composition of C&D material disposed of to landfill. This makes it difficult to analyse this data for advanced manufacturing, for example, as inputs into new products. Some data may be available through the NZ Green Building Council and past projects completed using the Infrastructure Sustainability Rating. This should be investigated in any future work.

It is likely data exists in the level of detail required for this project through existing advanced manufacturing facility-level waste management reports, although commercial sensitivity remains a limitation. Aggregated data could be requested from territorial authorities or waste service providers and facility operators, including Class 1 landfill waste levy data and inaugural reporting data available from Class 2–4 landfills. Additional analysis would be required to assess and verify industrial waste sources. This is beyond the scope of the current project.

A.4. Māori manufacturing

The ITP recognises opportunities for Māori workers, businesses, rangatahi and communities through the transformation of advanced manufacturing to support Māori-owned and Māori-led advanced manufacturing businesses.

Māori play an important role in the Aotearoa advanced manufacturing sector, and its future growth. As identified by Stats NZ, the number of people who identify as Māori is anticipated to grow to approximately 20% of the total population. There has been a consistent recognition of the need to have ongoing engagement with Māori as a key deliverable of this project. We have looked to utilise the He Waka Taurua framework, a research methodology that looks at how our work can be conducted collaboratively. The aim is that the findings from this project are relevant to Māori aspirations and include Māori economic opportunities.

Considerations and the project's commitments to Māori advanced manufacturing included:

- How we manage data gathering and engagement
- Place-making through geo-spatial mapping of advanced manufacturing sub-sector activities, to provide regional granularity relevant to iwi authorities (versus a national level lens)
- Ensuring findings from this project are relevant to Māori aspirations and include Māori economy opportunities
- Representation of Māori businesses within sub-sectors.
- This project is a part of the suite of MBIEs projects, including Project 0 Mātauranga Māori and Projects 1 and 2 of MBIE's Impacts, Barriers, and Enablers for a Circular Economy work programme.

A.4.1. Methodology

The guide to our research has been the He Waka Taurua framework. This framework helped to inform a way forward to align Western approaches to circular economy with te ao Māori principles, perspectives, insights, and influence. The goal was to not view the two approaches to circular economy in isolation, but understand the connections, and collaborative opportunities available within the advanced manufacturing sector between Māori businesses and other industry representatives regarding circular economy. With the focus on collaborative research and data gathering, it is imperative that findings have been sense-checked by the ITP's Māori Industry Action Group (MIAG) and with individual Māori businesses.

Our investigations into Māori businesses in advanced manufacturing were planned to be conducted in two phases. The first phase involved desktop research utilising available data from reliable sources. A second phase would cover industry stakeholder interviews to help provide a greater understanding of the businesses, the processes, and the whakapapa (genealogy) of the business. This further engagement would also help to uncover why there are limitations regarding available data, how Māori businesses may be impacted by the lack of data available, and what potential opportunities may be in place to build a greater collaborative circular economy.

The desktop research completed to date involved the collection of readily available data on the Māori economy from Stats NZ, MBIE, and similarly trusted sources. This research provided us with key information to understand geospatial locations, sub-sectors of operation and the economic contribution of Māori manufacturing within the wider manufacturing industry.

To successfully engage with Māori businesses, we ensured that we had appropriate data protection and identification of businesses prior to direct engagement. Ensuring data protection is in place is vital as discussions with Māori businesses should not be 'outcome focused'. We were focused on more open discussion and further consideration of the cultural context of their work and how it feeds into circular economy or impacts their waste as business'. Questions were altered to explore more about the whakapapa and priorities of the business, rather than the statistics.

We had looked to have one-on-one interviews with the business representative and allow time for follow up discussion and continued testing of findings with interested Māori businesses. However, due to rescoping needs in 2024 this part of the project was discontinued.

A.4.2. Māori data and Māori sovereignty

Historically, Māori data has been used to inform narratives and policy decisions about Māori, without Māori input or Māori values at the heart. Due to this, we understood the importance of ensuring that there was a strong data protection policy in place.

We recognise that Māori data is a taonga (treasure) and is a powerful tool to inform and drive significant change for the communities involved. Without engaging with Māori, we would not be able to gather insights into Māori whenua, people, and vision for the sector. This would result in untested and potentially inaccurate assumptions being made. Considering this, further engagement to gather more confirmed information from Māori business is necessary to ensure that Māori businesses are not inaccurately accounted for due to being overshadowed by the more readily available information for the non-Māori-owned businesses.

Māori data sovereignty ensures that we think deeply and critically about who collects data, why it is collected, how we ensure that data collection is safe for Māori, and that Māori are not excluded from its benefits. As with most Māori viewpoints, it is not about control, it is about care.

Some of the key considerations we have adopted in this project include:

- Better quality data about and for Māori using interviews which consider tikanga and Māori values.
- Māori determining what data is collected about and for Māori, and by whom.
- Important information like whakapapa, te reo Māori, mātauranga Māori and whenua information remaining in the hands of the iwi, hapū, whānau, and individuals it belongs to.
- Ensuring Māori oversight on the collection and use of sensitive information about Māori, like limited numbers of Māori businesses does not create a deficit narrative or disclose sensitive information.
- Ensuring data about Māori, including aggregate data, is collected, stored, and published in ways that consider Māori cultural and economic needs.
- Creating opportunities for Māori businesses to develop their own data collection methods.
- Empower Māori businesses to share their stories within the manufacturing sector.

A.4.3. Limitations and assumptions

There are several limitations and assumptions which require further engagement with Māori businesses to confirm findings. These are:

- There is a disparity of Māori manufacturing businesses reported between Stats NZ and MBIE. This disparity may be the result of an unclear definition of what constitutes a Māori-owned business, or if some Māori businesses are not accurately reflected within the existing ANZSIC codes and therefore fall outside of the manufacturing sector.
- Due to the smaller number of Māori manufacturing businesses accounted for in Stats NZ data, the ability to explore the sub-sectors or regions in which they operate is impacted. This is due to the information possibly leading to confidentiality breaches.
- There may be an unwillingness to take part in studies due to previous misuse of Māori data.
- As found through our research the limited available data has shown an increased need to engage with Māori within the advanced manufacturing sector to gather a more accurate reflection of Māori businesses in the sector.

A key challenge of this investigation is ensuring that the research is culturally reflective of Māori businesses and considers the values and contributions of te ao Māori principles within the work being undertaken by Māori businesses. All findings and assumptions need to be investigated further directly with Māori businesses, or they cannot be validated.

A.5. Industry engagement

A.5.1. Workshop

As part of the 'Mapping Emissions and Waste Stream Profiles, and Opportunities for Achieving Net-zero Circular Advanced Manufacturing' research project an online engagement workshop *Enabling a net-zero carbon circular Advanced Manufacturing sector - The Data Sessions* was held on Thursday 29 February, 2024.

The purpose of the workshop was to evaluate emissions and waste stream data mapping with stakeholders to gauge alignment with expectations and effectiveness in guiding business decisions within the seven advanced manufacturing sub-sectors. The priority sectors for MBIE were food and beverage, machinery and equipment and Other manufacturing – including textiles, furniture, cement, glass, ceramics. There was, therefore, an increased amount of data available for evaluation in these three priority sub-sectors.

The facilitated workshop was hosted online to provide an accessible platform for industry representatives to attend and participate. General findings were shared and tested during the plenary session. Following this, the group separated into sub-sector breakouts to explore sub-sector-specific findings and questions through interactive activities. These sessions also identified preferred stakeholders for subsequent interviews.

Invitations were sent to an even spread of stakeholders in January and February across the seven advanced manufacturing sub-sectors. The aim was to have four to six businesses per sub-sector, with at least one of the following criteria being met by one or more of the businesses:

- SME (Between 0 – 49 FTE employees)
- Large organisation (more than 50 FTE employees)
- Māori owned / iwi affiliated
- Rural

The online workshop had 73 registrations and 69 Zoom attendees including technical support and facilitators. It opened with a plenary session explaining the context of the workshop and NZ manufacturing context, and provided a general overview of national-level data collected to date. Attendees were then able to breakout into virtual rooms for each of the following sectors:

- Food and beverage
- Machinery and equipment
- Metals and metals products
- Paper and wood
- Plastics and rubber + chemicals and refining
- Other manufacturing – including textiles, furniture, cement, glass, ceramics
- General – working across sub-sectors

Sector-specific data and mapping was shared by a facilitator in each breakout room, with participants asked to reflect on the following questions:

1. Is the data/mapping what you expected and why is that?
2. What parts of the data/mapping are interesting and why?
3. Is there missing information that would be useful? If so, what?
4. How might we get that data?
5. What opportunities does the data/mapping reveal for achieving a net-zero circular sector?
6. What needs does the industry have in managing the transition to a circular economy?

Facilitators recorded ideas and questions on a shared Miro board, and then shared a summary of the discussion back with the wider group.

A.5.2. Interviews

In developing our report on advanced manufacturing in New Zealand, Aurecon, SBN, and thinkstep-anz undertook a comprehensive methodology for conducting stakeholder interviews. This was necessitated by previous work, which exposed numerous gaps and inconsistencies in publicly available data on material flows within the sector.

The stakeholder interviews were conducted to address these data gaps, identify non-confidential alternative data sources, validate our assessment assumptions, and enrich the context of our project's final deliverables. Interviews were targeted across seven sub-sectors within the New Zealand advanced manufacturing supply chain: food and beverage, machinery and equipment, wood and paper, metals and metal products, chemicals and refining, plastics and rubber, and other manufacturing.

Pre-interview preparations involved creating sub-sector-specific questions, drawing upon data gaps identified through combined top-down and bottom-up mapping efforts, and insights from a stakeholder workshop held on 29 February 2024. An MBIE-approved 'infosheet' about the project was distributed to participants before the interviews to provide context and reduce the need for explanatory discussions during the interviews.

Interview candidates were selected based on their sector knowledge, covering industry leaders, academic researchers, policymakers, and practitioners. The aim was to conduct three to four interviews per sub-sector, with a total cap of 24, prioritising candidates based on their potential contribution.

The online interviews sought to gather comprehensive business profiles from participants, including job roles, business activities, size, and locations. An emphasis was placed on open and closed-ended questions tailored to identify data gaps and validate project assumptions. Interviewees were encouraged to highlight any information they wished to remain confidential. Each session lasted between 40 and 60 minutes, including introductions, questions, and wrap-up time.

Following the interviews, a rigorous data analysis and synthesis process was undertaken to highlight common themes, unique insights, and additional data sources identified during the discussions. These findings have been integrated into the Engagement Report and the final project deliverable, with support from SBN.